ИЗВЕСТИЯ
АКАДЕМИИ НАУК СССР
СЕРИЯ ГЕОЛОГИЧЕСКАЯ

IZVESTIYA AKAD. NAUK SSSR

SERIYA GEOLOGICHESKAYA

1959 No. 3, March

CONTENTS

T-08808 Approved for printing February 20, 1959
Circulation - 4200 copies. Order 3379.
Paper size 70 x 108-1/16 Paper 4. Printing sheets 10.96 + 2 ins. Publ. sheets 12.8

Second printing office of the USSR Academy of Sciences Publishing House
Moscow, Shubinskiy per. 10.

LATE PRECAMBRIAN DEPOSITS OF THE AMUNDSEN AND SANDAU MOUNTAINS ON QUEEN MARY LAND, EASTERN ANTARCTIC[1]

by

P. S. Voronov, L. V. Klimov, and M. G. Ravich

INTRODUCTION

This paper is the first nonofficial publication from the office processing material of the 1956-1957 Soviet Antarctic Expedition. It discusses a very rare group of late Precambrian metamorphic facies of green schists. These were first discovered in the central eastern sector of the Antarctic where previously only crystalline schists and gneisses of the granulite metamorphic facies had been known to exist.

The Amundsen and Sandau Mountains are located 200 km south of the northern oceanic shore of Ice Island Mill, or 100 to 120 km south of the Bunger Oasis. Both mountains are located on the right side of the upper reaches of the Denman Glacier, with a nunatak chain on the opposite side 50 km to the west: Garan, Stratcone, and Barr-Smith. The Amundsen Mountain coordinates are 67° 22' S. latitude, and 100° 22' W. longitude (Fig. 1).

Both mountains were discovered by the eastern party of the Mawson expedition, December 19, 1912 [2].

A geologic reconnaissance of these mountains was made in January 1957 by L. V. Klimov and P. S. Voronov who described the stratigraphic section diagrammatically and collected 70 samples [1].

Their material was processed by the Scientific Research Institute of Arctic Geology. The petrographic description was by M. G Ravich in collaboration with Ye. M. Orlenko; the complete silicate analysis of the Sandau schists was performed by A. Z. Shpindler; the absolute age was determined in the Precambrian Geology Laboratory, Academy of Sciences, U. S. S. R. under the direction of E. K. Gerling.

MORPHOLOGY OF THE MOUNTAINS

Orographically, the Amundsen and Sandau Mountains are typical nunataks rising above the Antarctic ice shield, the first, 50 m, the second 150 m (Fig. 2, 3). The absolute elevation of the Amundsen Mountain is 1, 445 m; of the Sandau, 1, 380 m. The difference in height is probably the result of the proximity of the Sandau Mountain to the edge of a clearly defined depression of the Denman Glacier -- a mighty ice flow, about 20 km wide and more than 200 km long. The glacier carries enormous masses of ice toward the Indian Ocean, along a bed lined by nunatak chains. Its ice surface is crisscrossed by fractures genetically connected with the progress of ice. Many fractures are also located in the immediate vicinity of the glacier, especially in the vicinity of the two mountains. The cracks locally are more than 200 m wide. They evidently are the result of the uneven surface beneath the shield. The shield itself moves seaward, although more slowly than the Denman glacier. Judging by its morphologic features, this glacier corresponds to an enormous fjord, trending submeridionally, on the subglacial Antarctic relief.

Because of the monoclinal position of their rocks, the Amundsen and Sandau summits are comblike, and cuestalike in crosssection. The crest of the Amundsen Mountain, above the ice, is sicklelike in plan, about 800 m long and about 160 m wide. The Sandau crest is hooklike in plan, with a steep northern slope, about 350 m long, and an eastern shelf about 600 m long. The middle part of the exposed body is 100 to 120 m wide.

Judging from the fracturing pattern, the Sandau Mountain is being bypassed in the southwest by a glacier moving northwest. The axis of that flow, corresponding to the lowest part of its bed, lies about 1.5 km from the summit. A similar glacier bypasses the Amundsen Mountain to the south and southeast. Its edge is 2 km from the mountain.

Both mountains are formed by an alternation

---

[1] **Pozdnedokembriyskiye otlozheniya gor Amundsena i Sandau na zemle korolevy meri v vostochoy antarktide.**

FIGURE 1. Index map of the Amundsen and Sandau Mountains, in Eastern Antarctic.

1 -- limit of continental ice; 2 -- outgoing glaciers; 3 -- shelf ice; 4 -- migmatized schists and gneisses of the granulitic metamorphic facies; 5 -- metamorphosed extrusive-terrigenous rocks of the green schist facies; 6 -- strike and dip of metamorphic terrigenous rocks; 7 -- assumed faults; 8 -- precipitous ice cliffs.

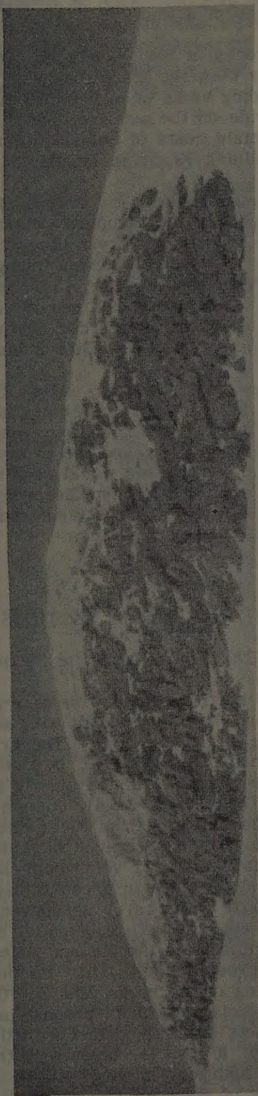


FIGURE 2. Mt. Amundsen as seen from northwest, 0.3 km away (Photo by P.S. Voronov)

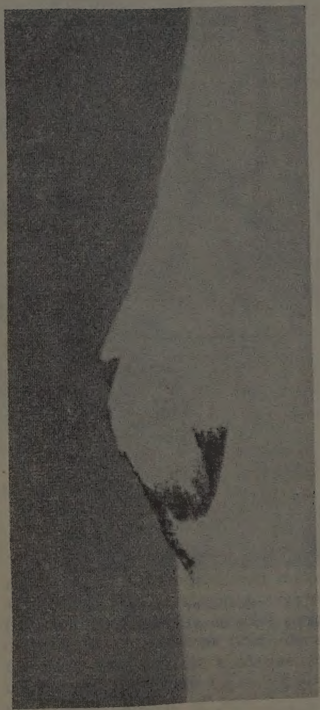


FIGURE 3. Mt. Sandau as seen from northwest, about 0.5 km away (Photo by P.S. Voronov)

of crossbedded, unevenly altered terrigenous rocks represented by argillites, siltstones, sandstones, and conglomerates (Fig. 4). Their total thickness is in the order of several hundred meters. In the Sandau section, this sequence is underlain by green schists, eight meters of which are visible above the ice.

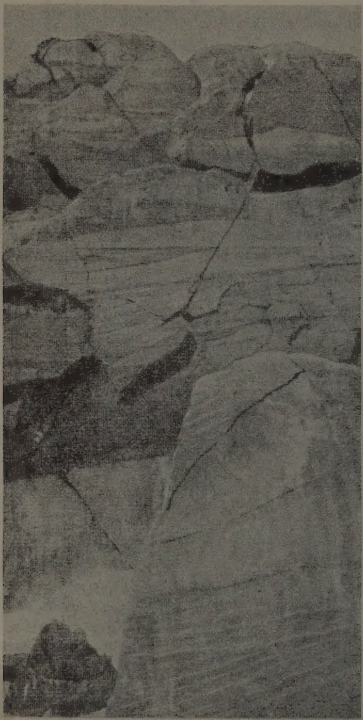


FIGURE 4. The character of bedding in an Amundsen Mountain section (Photo by P.S. Voronov).

The Sandau sequence has a fairly consistent submeridional strike and an easterly dip, changing from 40° at the base to 25° toward the top. Similar rocks in the Amundsen Mountain strike east-northeast, dipping south-southeast at 15° to 25°.

As will be shown below, the sections of both mountains belong to the same sequence, with higher beds exposed in the Amundsen Mountain. This is also reflected in its higher elevation.

Assuming that the two mountains are not separated by a major fault, it may be supposed that these metamorphic terrigenous rocks form here the northwestern part of the centrocline of a major synclinal fold whose axis, of a submeridional trend, plunges southward to the interior of the continent. This last assumption is based on flatter dips of the Amundsen Mountain terrigenous rocks, which are best explained by their proximity to the axis of a fold.

The rocks in both mountains are broken by numerous cleavage fractures, with fairly common bedding veins of milk-white quartz, 10 to 15 cm wide on the average. Some of the veins contain nests of colorless quartz crystals, attaining 10 cm in length.

The comparatively low degree of regional metamorphosed and complexly dislocated Precambrian migmatized crystalline schists and gneisses, exposed in outcrops along the west side of the Denman glacier [1]. This justifies their assignment to a new structural stage of the eastern Antarctic platform, higher than that of the crystalline schists.

A sharp straight bench, about 100 m long, traceable along the west side of the Denman Glacier, may be explained by a major regional fault which determined the orientation of the glacier fjord. This would readily explain the above-mentioned sharp discordance in the strike of the crystalline schists and the metamorphosed terrigenous rocks.

STRATIGRAPHIC SECTIONS

a) The Sandau Mountain Section

1. The section begins with dark-green slaty chlorite-epidote schists with scattered fine pyrite and chalcopyrite. The green schists are cut, nearly everywhere, by thin veins of milk-white quartz, oriented chiefly along the bedding. These veins locally contain vugs with a brushlike growth of clear quartz crystals and coarse incrustations of pink-brown calcite. Similar quartz veins commonly cement the brecciation zones in green schists. Larger quartz-calcite veins carry an appreciable amount of epidote, with substantial epidotization also present in the contact zones of the enclosing green schists. The well-defined slaty parting of the rocks dips S. 70° E. at 40°. A brecciated zone is present in the green schists at their contact with the overlying rocks. It also is cemented with vein quartz. In addition, it shows slickensides with traces of epidote. The exposed green schist section is about 8 m thick.

2. The green schists are overlain by a conglomerate bed of small, rounded pebbles, as much as 5 cm in diameter, chiefly of white, gray, and light-lilac quartz and gray

to pinkish, banded, fine-grained quartzites (Fig. 5). Less common are smaller and rougher pebbles of the underlying green schists. The conglomerate is cemented by an unevenly grained metamorphosed sandstone consisting chiefly of well-rounded quartz grains cemented by a quartz-chlorite-sericite material, with scatterings of fine hematite. The sandstone content in conglomerate is 20 to 60 percent. The conglomerate dips S. 75° E., at 40° and is 0.6 m thick.

quartzitic sandstone with distinct thin intercalations of cherry-brown, ferruginous siltstones. The sandstone grains are medium to well rounded and sorted, locally with gravelsize grains. The cement is marked by numerous scatterings of ore minerals. The entire bed is characterized by a sharp cross bedding of the temporary water-current type; the average dip is S. 60° E., at 45°. The bed is about 12 m thick.

FIGURE 5. Basal conglomerate; the Sandau Mountain section. (Photo by P.S. Voronov).

3. Higher up, there is an alternation of metamorphosed conglomerates with quartz and quartzite pebbles, and quartzitic sandstones. These conglomerates differ from those below by the absence of chlorite in the cement and by the disappearance of the green schist pebbles. Instead, the cement of some intercalations, especially toward the top, has been enriched by hematite and limonite grains, with some small pebbles of pink feldspar and cherry-brown argillite. The thickness is about 5.5 m.

4. A bed of unevenly grained pinkish-gray quartzitic sandstone with thin (as much as 10 cm) intercalations of charry-brown ferruginous siltstones and argillites. The quartzitic sandstones are characterized by two types of cross bedding: the water-current type in the upper and lower parts, and the eolian in the middle (Fig. 6). This bed is about 12 m thick.

5. An uneven-grained, greenish-gray

6. A rhythmic alternation of quartzitic sandstones, metamorphosed siltstones, and argillites. The sandstones are medium to fine grained, usually banded, with the bands of different colors, as much as 2 cm wide. Locally, they exhibit a coarse crossbedding of the water-current type. They carry, at their base, lentils of interformational conglomerates with unsorted ellipsoidal pebbles of cherry-brown ferruginous argillites and similar siltstones, from 20 cm to 1 m thick. This bed is about 35 m thick, with an average S. 60° E. dip, at 35°.

7. Medium- to coarse-grained, pinkish-brown, massive quartzitic sandstones. The entire bed and the contact parts of the adjacent beds are cut by veins of milky quartz, 5 to 30 cm thick, locally bearing crystals of clear quartz, 1 to 2 cm long, in brushlike growths. This bed is about 5 m thick.

8. A rhythmic alternation of quartzitic sandstones, metamorphosed siltstones, and

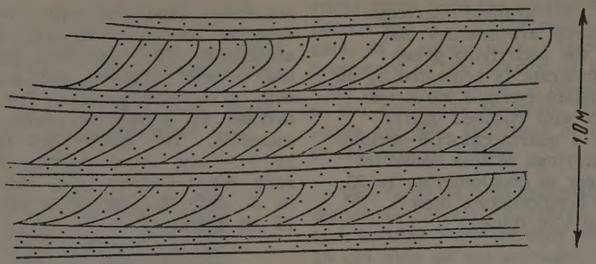


FIGURE 6. Cross bedding of the temporary stream type; lower part of the Sandau Mountain section. (Sketch by P.S. Voronov).

argillites, similar to bed 6. In the middle part, about 10 m thick, crossbedded sandstones alternate with massive pinkish-gray medium-grained quartzitic sandstones. They, as well as the adjacent bedded sandstones, are cut by numerous thin veins of quartz, locally crystal-bearing. The bed is about 40 m thick, with an average S. 85° E. dip at 30°.

9. Quartzitic sandstones, similar to bed 7, but with 0.2 to 0.3 cm thick intercalations of thin sericite schists. The visible part of the bed is about 10 m thick, dipping S. 85° E., at 25°.

b) The Amundsen Mountain Section

1. Arkosic sandstone, metamorphosed, medium to coarse grained, locally polymictic, with a banded texture, caused by an alternation of cherry-brown (more ferruginous) and pinkish-gray layers. Layers of cherry-brown metamorphosed siltstones and argillites, as much as 0.5 m thick in the upper part. Rounded pebbles of these rocks (especially of argillites) commonly form thin (as much as 10 cm) beds (Fig. 7). There are numerous slickensides, dipping due west at 45°. The dip of the bed is S. 10° E., at 25°. Thickness is about 30 m.

2. Massive arkosic sandstone, medium to coarse grained, metamorphosed, with numerous veins of white quartz along the bedding planes, commonly carrying druses of smoky and clear quartz crystals. The crystals attain 10 cm in length and 5 cm in diameter. The veins are as much as 0.4 m thick. A sharp contact with the overlying cross bedded sandstones dips S. 15° E., at 15°.

3. A bed similar to bed 1, but with the cherry-brown ferruginous siltstones and argillites getting thicker, as much as 1 m, and becoming more numerous. The apparent thickness is about 20 m.

A correlation of the two sections leads to the following conclusions:

1. In their general aspect, the Sandau Mountain terrigenous metamorphic rocks are similar to those of the Amundsen Mountain section. They both are characterized by a rhythmic alternation of beds.

2. The contact of the Sandau terrigenous metamorphics with the underlying green schists is marked by a stratigraphic break, complicated by subsequent faulting and the injection of quartz veins.

3. On the whole, the middle and lower parts of the Sandau metamorphic terrigenous section are marked by a sharp predominance of quartz over feldspar within the clastics that make up the sandstones. The clastic grains generally are average to well sorted and rounded. The argillite beds are thicker and more numerous than in the Amundsen Mountain section. There are layers of sericite schists, thus making the rhythms better expressed in a whole gamut of terrigenous rocks, from conglomerates and sandstones to siltstones, argillites, and sericite schists. The dips are generally from 30° to 45°.

4. Quartz is less conspicuous in the clastic material of the Amundsen Mountain terrigenous metamorphic section, because of the higher feldspar content (as much as 40 percent), including K-feldspars. The rounding and sorting of grains is average to poor. The entire section is very sandy, with well developed interformational conglomerates. Sericite schists have been noted only in the conglomerate pebbles. Here, the rhythms are incomplete, which is emphasized, in many places, by the absence of fine- to very fine-grained varieties, resulting from syngenetic erosion. Average dips are 15° to 25°.

5. In its lithology and dips, the upper part of the Sandau section (beds 8 and 9) is similar to the Amundsen section. However, the

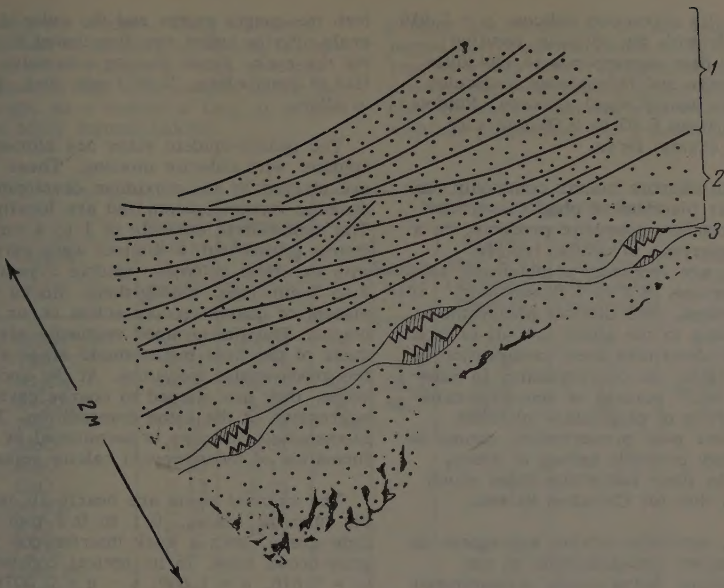


FIGURE 7. Crossbedding of the eolian type, in metamorphosed sandstones of Mt. Amundsen, and the position of quartz veins (Sketch by L.V. Klimov).

1 -- cherry-brown crossbedded arkosic sandstones; 2 -- gray, nonstratified arkosic sandstones; 3 -- veins of milky quartz with druses of smoky and clear quartz crystals.

lithologic and structural differences between the upper and the middle and lower parts of the Sandau section suggest a sedimentary break.

PETROGRAPHIC DESCRIPTION

As a result of petrographic study, the metamorphics of the Amundsen and Sandau Mountains may be divided into five main groups; 1) metamorphic basalt rocks altered to epidote-chlorite schists with quartz-epidote and chlorite veins; 2) metamorphic quartz conglomerates; 3) assorted metamorphic quartz-feldspar and quartz sandstones, locally reminiscent of quartzites; 4) metamorphic siltstones and argillites; and 5) sericite schists.

We turn now to the description of each group.

1. Green schists (metamorphic basalt rocks) are thinly tabular, locally brecciated and cemented with quartz veins carrying epidote and chlorite. They are heteroblastic, with a preponderance of granoblastic and nematoblastic elements, and with local remnants of ophitic and porphyritic textures. In the latter instance, a relict intersertal texture occurs in the groundmass, which gives the rock a basalt porphyrite aspect.

The composition of green schists is fairly uniform, although the quantitative ratios of rock-forming minerals varies considerably, being 30 to 50% for chlorite; 20 to 35% for epidote, together with the sossurite aggregates; 3 to 10% for actinolite and uralite hornblende; 1 to 6% for calcite; 10 to 15% for ore minerals (leucoxene and hematite, with a few relict grains of titanomagnetite); 1 to 5% for quartz in lenses and druses; rare sericite scales, and some relicts and prismatic tablets of plagioclase, as much as 10%.

The main fabric of the rock consists of fine-grained chlorite aggregates, with crystal aggregates of epidote and clots of sossurite among them. The whole is threaded with fine tablets of dirty gray uralite and sheaves of light-green actinolite spicules. The chlorite is pale blue showing a poor

interference. Its refraction indices, $\gamma = 1.619$ and $\alpha = 1.616$; with the optically positive mineral, this best corresponds to ripidolite where magnesian and ferruginous molecules are present in nearly equal amounts. Epidote forms grains from 0.03 to 0.05 mm with two or three crystal faces.

The epidote-chlorite matrix commonly contains columnar platelets of plagioclase, replaced by secondary sossurite products, in a lattice characteristic of ophitic texture. Locally there are remnants of prismatic tablets of plagioclase, 0.3 to 1.0 mm long, commonly broken, with distinct polysynthetic twins, according to the albite law. It is locally possible to determine their composition on the Fedorov table, as corresponding to andesine with 30 to 37 percent of anorthite molecule. The relicts of plagioclase platelets because of their poor preservation, cannot be identified. They probably belong to albite, as indicated by their refraction index which is lower than that for Canadian balsam.

As a rule, actinolite-uralite aggregates do not form complete pseudomorphs on the pyroxene crystals, being evenly disseminated throughout the rock. However, relicts of monoclinic pyroxene have been preserved in isolated instances. They cannot be more closely identified because of the state of their preservation. Aggregates of ore minerals occur as in crystallized basalt or fine-grained dolerite. They are formed by small jagged grains, a mere outline of former titanomagnetite now replaced by cloudy leucoxene and brown, barely transparent, hematite. Pyrite crystals, 0.3 to 0.5 mm long, are uniformly disseminated throughout the rock and represent the secondary ore mineral.

Quartz and calcite occur in the green schists in bizarre forms of fine lentils or threadlike veins, 1 to 2 mm thick. Quartz grains, as much as 0.5 mm long are strongly jagged and show a distinct wavy extinction. The calcite grains are well shaped and marked by crisscrossing polysynthetic twins, at times nearly completely filled with light-green, scaly chlorite.

Epidote-quartz and chlorite veins only a few centimeters thick and transverse to the beds which are more than 10 cm thick, are fairly common in green schists. The quartz veins are 80 to 90% crushed and contain jagged quartz grains, 2 to 5 mm long. The remaining 10 to 20% are accounted for by chlorite, epidote, actinolite, calcite, leucoxene, and some plagioclase. The colored minerals are concentrated locally in sinuous, veinlike aggregates, whereas the calcite seals the threadlike cracks in coarse quartz grains, actinolite spicules uniformly pierce both the quartz grains and the colored minerals. Pyrite cubes are distributed throughout the rock. Fresh-looking prismatic tablets of plagioclase, 2 to 3 mm long, belong to albite.

The quartz-epidote veins are almost half epidote, with chlorite missing. These veins are marked by the maximum development of dynamic metamorphism and are locally slaty. The vein matrix consists of 1 to 4 mm long quartz grains with a distinct wavy extinction, with excellent columnar epidote crystals, 2 to 3 mm long, among them. Rocks reminiscent of quartz-epidote schist occur in places. The fine-grained segments are products of the first metasomatic stage along the green-schist fractures. At the second stage, they are altered to coarse-crystalline aggregates of the same composition. The metasomatic process is terminated by the formation of monomineral calcite veins.

The chlorite veins are nearly all isometric chlorite scales, 0.1 to 0.2 mm wide, light-green, with a weak interference in odd gray-brown hues. In its optical constants, ($\gamma = 1.616$, $\alpha = 1.609$, $\gamma - \alpha = 0.007$), the optically positive chlorite corresponds to prochlorite, characterized by the preponderance of magnesian components over the ferruginous. In this respect, the vein chlorite differs from the green-schist chlorite in a lower iron content, which is probably the result of the latter's metasomatic mobility. The chlorite matrix contains reworked remnants of green schists, 2 to 5 mm in size, consisting chiefly of epidote and leucoxene. They are fringed by quartz granules.

All these veins, formed along fractures and slaty partings, are most probably metasomatic in nature. The fact is, that, at the final stages of the fracture-contact metasomatism, such elements as iron and magnesium, followed by silicon, are fully mobile. Thus emerge abundant monomineralic quartz, epidote, and chlorite veins, and sills of epidote rocks.

The chemical composition of the typical Sandau Mountain schist is very close to that of normal basalt. The analysed sample No. 1181 is 32% chlorite, 21% epidote, 8% actinolite, 12% leucoxene, 20% quartz, 5% relicts of plagioclase No. 37 tablets, and 2% calcite.

A comparison of the chemical compositions of the Sandau green schists and the average basalt, after R. Daly, shows that, despite its metamorphism, the green schist differs but little from basalt; the difference being the leaching of alkalis and partly of silica in the process of metamorphism. The numerical characteristics of typical basalts, according to various authors, are similar to those of

the Sandau green schists. They confirm a certain amount of leaching of alkalis in the metamorphism of feldspars. This accounts for the apparent high lime content in the latter; although, as a matter of fact, it is present in the newly formed calcite.

pebbles are formed by closely contacting jagged quartz grains, from 0.05 to 1.5 mm long with very fine fragments of zircon present everywhere. The green-schist pebbles are mostly chlorite with relicts of albitized plagioclase and a scattering of ore minerals.

Oxides	Sample 1181 (% by weight)	Average basalt, after R. Daly	Numerical characteristics				
				Sample 1181	Basalts after F.Yu. Levinson-Lessing	Average basalts, after A.N. Zavaritskiy	All basalts, after R. Daly
SiO_2	45.79	49.06	a	7.0	7.5	9	9.2
TiO_2	2.51	1.36	c	8.4	7.0	6	6.1
Al_2O_3	16.55	15.70	b	26.3	26.6	27	26.8
Fe_2O_3	6.16	5.38	S	58.3	58.9	58	57.9
FeO	7.30	6.73					
MnO	0.42	0.31					
MgO	6.50	6.17					
CaO	7.13	8.95					
Na_2O	2.67	3.11					
K_2O	0.45	1.52					
P_2O_5	0.25	9.45					
Loss in heating	4.84	—					
Total	100.57	—					

The original magmatic nature of green schists is not doubted. It remains obscure, however, whether they were basalt sheets, comparatively well crystallized as a whole, or that the green schists were formed from ancient sill traps.

The metamorphism of these rocks is typically regional, corresponding to the "green schist" facies. This facies is, by far, not as deep-seated as the so-called "granulitic," which includes the Antarctic crystalline shield gneisses. The green schists are marked by a paragenesis of chlorite with epidote, with an increase in calcite and the disappearance of actinolite in acid plagioclase. It is most probable that they are younger than the much deeper gneisses of the eastern Antarctic.

2. Metamorphosed quartz conglomerates. Their pebbles consist chiefly of quartz of various textures and origin. Less common are pebbles of typical quartzites with isolated green-schist pebbles. Quartz pebbles, as a rule, are markedly cataclastic, commonly with a mosaic and less commonly a radiate texture. Comparatively large (as much as 3 mm) crystalline quartz grains are located in the center of the radiate aggregates. They obviously are of vein origin. Scales of sericite and less commonly of chlorite are developed in the extremely fine fissures in the quartz grains. The quartzite

These conglomerates are chiefly cemented by quartz-sericite, locally carrying numerous chlorite scales and abundant limonitized ore aggregates. Less common is a fine-grained quartz aggregate cement, with rare scales of chlorite and sericite; there are a few instances of cement consisting of unevenly grained sandstone and quartzite. The conglomerate cement everywhere contains clastic grains of tourmaline, zircon, and rare sphene. Their size does not exceed 0.1 mm in length.

The quartz-sericite cement has probably been formed as a result of the recrystallization of siliceous-argillaceous aggregates. As a result, the sericite scales form bizarre aggregates, surrounded by fine-grained, unevenly crystallized quartz grains, at times in opallike formations. The quartz aggregates are slightly limonitized. With ore components present in the original siliceous-argillaceous cement, its recrystallization is accompanied by the appearance of a quartz-sericite-chlorite cement, with sericite and chlorite scales, 0.05 to 0.2 mm long, which either form local accumulations or fringes about the pebbles. The space between the pebbles are filled with fine-grained quartz and limonitized ore aggregates.

The metamorphism of quartz and associated

conglomerates is expressed, first of all, in an intensive recrystallization of the cement, and in a partial recrystallization of the pebbles. Fine-grained aggregates of quartz and sericite and chlorite scales are formed from the siliceous-argillaceous-ore products. Such a paragenesis of minerals corresponds to low-temperature associations of the "green schist" facies. It may be assumed to have been formed in the process of regional metamorphism.

3. Metamorphosed quartz sandstones, locally changed to quartzites. Fine-to medium-grained quartz sandstones, with a low feldspar grain content (5 to 10 percent) predominate among the Sandau and Amundsen metamorphic terrigenous rocks. They change gradually to unevenly grained, in places, coarse, quartz-feldspar sandstones, with the feldspar grains accounting for 15 to 20 percent of the rock volume. The sandstone texture is psammitic, changing to mosaic, as a result of partial recrystallization. Cement mechanically fills the pores; being considerably recrystallized, it acquires a blastopsammitic texture; and a lepidoblastic texture, in the presence of abundant sericite. The clastic material predominates over the cement, accounting for 60 to 80% of the volume, as against 20 to 30%, in a few places 40%, for the latter.

The clastic material is represented by well-sorted quartz grains, medium well rounded, and by considerably less numerous feldspar grains, 0.1 to 0.4 mm. This makes it possible to differentiate fine- and medium-grained varieties.

The feldspar grains are isometric and tabular, not as well rounded as the quartz grains. As a rule, feldspar has been intensely altered, sericitized and sossuritized. Although it does not exhibit a twin structure, it may be identified as plagioclase from the products of its alteration. Fine-grained quartz aggregates locally replace the plagioclase grains, as a part of the overall metamorphism of sandstones. A few fragments of siliceous rocks, more or less recrystallized, occur in the clastic material, along with rare sericite-schist pebbles, 0.2 to 3 cm long, in places as much as 5 cm.

Individual sandstone specimens carry large accumulations of clastic tourmaline grains, as much as 2 percent of the total volume. The grains are mostly rounded, 0.02 to 0.2 mm in size. The tourmaline is deeply colored, with a strong pleochroism in green and blue, rarely brown, hues. Zircon, in semiangular, short columnar crystals, as much as 0.1 mm, is a constant accessory mineral.

Considerably less common are very fine grains of sphene and hornblende, which are sporadic accessory minerals. The identical composition of the clastic material -- including the accessory minerals -- of these conglomerates and sandstones points to their common origin.

The cement of quartz sandstones is almost all quartz-sericite, locally strongly limonitized. Sericite scales are disseminated among the quartz aggregates, but they occur more commonly in fringelike concentrations about the sand grains.

3a. Metamorphosed arkosic sandstones externally are not unlike the quartz sandstones, except for the appreciable local increase in the size of sand grains, as much as 1.5 mm, the increase in clastic material (75 to 85%), and a decrease in the cement content (15 to 25%). The composition of their clastic material is, however, substantially different, with the K-feldspar content (as much as 20%) higher than that of plagioclase. In isolated beds, the content of quartz-sericite schist, microgranite, and sericite-chlorite schist reaches 15%, thus actually forming polymictic sandstones.

Quartz occurs usually in semiangular, semirounded grains, always cataclastic, 0.1 to 2.0 mm, with the coarsest ones exhibiting a mosaic structure. The numerous fractures in the grains are filled with ore aggregates.

K-feldspar is represented by semirounded tabular grains, 0.2 to 0.7 mm, usually 0.5 mm long. As a rule, the grains are strongly pelitized, which makes their twin microcline lattice inconspicuous.

Plagioclase occurs in finer, strongly sericitized, and better rounded grains.

These sandstones are exclusively cemented with quartz-sericite, little different from the quartz sandstone cement, except for fine (0.1 mm) clastic grains of zircon and tourmaline, more angular and less numerous than those of similar accessories in the quartz sandstones.

4. Metamorphosed siltstones and argillites. Metasiltstones are related to fine-grained sandstones by a series of gradual transitions inasmuch as their sandy fraction is as much as 30%. They are represented by cherry-brown, dense, silty to silty-sandy rocks. The clastic material, to the amount of 80 to 90% of the overall volume, is represented by semirounded grains of assorted sizes, from 0.03 to 0.6 mm, with the silty fragments, 0.03 to 0.05 mm, predominating considerably over the sandy ones. Cement is

unevenly distributed in the siltstones, where it occurs only locally in thin bands, accounting for only 10 to 20% of the volume. It consists of sericite scales, minute grains of quartz, and comparatively rare dustlike accumulations of ore minerals. Quartz is the most abundant among the clastic minerals, with a several times smaller amount of sericitized plagioclase in semirounded grains. There are isolated scales of muscovite and fragments of sericitized argillite.

Metamorphosed argillites are represented by very dense cherry- to dark-brown rocks. Their texture is pelitic, becoming microgranoblastic in isolated sectors, as a result of partial recrystallization. The argillite-sandstone contacts are sinuous, although fairly sharp, with veinlets of pure sericite along them; the fractures in both rocks, near the contact, are filled with threadlike quartz veinlets, locally carrying chlorite.

5. Sericite schists are distinctly slaty rocks, pinkish to gray yellow, typically microblastic, consisting almost wholly of sericite scales, elongated in one direction in thin sinuous bands. Besides rare clastic grains of quartz and its fine-grained aggregates, there are small angular grains of tourmaline and zircon, and coarser grains of ore minerals.

In their original composition, the metamorphics of the Sandau and Amundsen Mountains are subdivided into two genetic groups: a) volcanic, formed from basalt flows, and b) terrigenous, formed from psephitic-sandy silty sediments. Both have undergone changes under the conditions of "green schist" facies, typical of regional-metamorphic processes, comparatively shallow and proceeding at low temperatures. The metamorphism of basalt rocks is more complete than that of the terrigenous deposits, primarily because of their more complex composition as compared to the predominating silica content of the latter. Consequently, clastic rocks with a sharp preponderance of quartz have been merely recrystallized, with the silica-argillaceous cement fully replaced by the newly formed sericite scales with a small amount of chlorite and aggregates of fine-grained quartz. The paucity of mineral parageneses in the metamorphism of terrigenous rocks is related to the absence of carbonate deposits in the latter.

CONCLUSIONS

1. Although direct contacts are lacking between the metamorphosed extrusive-terrigenous rocks, which we discovered in the area of the Amundsen and Sandau Mountains, with gneisses and crystalline schists of the central part of the eastern Antarctic coast, it may be stated that the former are younger than the latter, and were formed under quite different geologic conditions. Both sequences differ from each other, not only in the character of their metamorphism but in the folding and igneous activity.

2. The Sandau green schists may be similar to the green-schist formations of the Taimyr Peninsula and a number of east-Siberian areas (Baikal and Patomsk-Daban uplands, eastern Sayans, Khamad-Daban, etc.), also to the Karelian formation of the Kola peninsula and Karelia. In all these areas, the green-schist formations are supposed to be Proterozoic. For the time being, we consider the Sandau green schists to be the same age.

3. A correlation of the Sandau and Amundsen metamorphic terrigenous sequence with similar composition, geologic position, and character of metamorphism makes late Precambrian the most probable age for the Siberian sequences. This has been confirmed using the argon method of the absolute-age determination for sample 1178-I of a schistose fine-grained quartz sandstone with abundant sericitic cement. The figure so obtained was 560 million years.[2]

The presence of a stratigraphic break between the green schists and overlying terrigenous rocks, as well as of conglomerates at the base of the latter, suggests their different age. If the green schists are probably Precambrian, the terrigenous sequence may be Sinian.

4. Arenaceous sediments predominate in the terrigenous deposits, with psephitic, silty, pelitic deposits not as well developed. The poor sorting of the clastic material is characteristic, with the result that sediments of different grain sizes occur locally in the same bed. In addition, small conglomerate lentils and isolated pebbles of rocks from the lower part of the sequence occur among the upper beds. This indicates a multiple erosion and redeposition of the terrigenous beds.

5. It is significant that sandstones with a greater content of K-feldspar fragments are associated with the Amundsen Mountain section and with the upper terrigenous metamorphics of Sandau Mountain where they form

[2] The age of terrigenous rocks, as determined by the K-Ar method, is the age average of the K-carrying minerals, syngenetic as well as those entering the sediments in the destruction of older rocks of various ages. Russian Editor.

the thickest beds, whereas quartz sandstone predominate in the lower part of the section. Thus, it may be surmised that the source of the sediments shifted appreciably closer to the sedimentation area in the period of the upper-sequence deposition, thus putting a new emphasis on K-feldspar, which is considerably less stable than quartz. As to the composition of these later source rocks, it apparently remained unchanged, being determined by granitoids and their vein facies, both characterized by a preponderance of K-feldspar and a considerable quartz content.

6. The source of the quartz and associated pebbles in the conglomerates may have been any disintegrating coarse granite and accompanying pegmatitic and quartz veins, including the metasomatic granite and associated veins in crystallines of the Antarctic Precambrian. These source rocks were probably located at some distance away from the conglomerate site, as indicated by the well-rounded and well-sorted pebbles; they are rather uniform in composition, being represented chiefly by quartz, the most stable mineral capable of withstanding a long travel.

7. Judging from their lithologic features, these terrigenous metamorphics were originally deposited by water and partially by wind, under littoral continental conditions.

REFERENCES

1. Ravich, M. G. and P. S. Voronov, GEOLOGICHESKOYE STROYENIYE POBEREZH'YA VOSTOCHNOY ANTARKTIDY (MEZHDU 55° AND 110° VOSTOCHNOY DOLGOTY) [GEOLOGIC STRUCTURE OF THE EAST COAST OF THE ANTARCTIC (BETWEEN 55° AND 110° E° LONGITUDE)]: Sov. Geologiya, no. 2, 1958.

2. Mawson, D., AUSTRALASIAN ANTARCTIC EXPEDITION, 1911-1914: Geogr. Journ., v. 44, no. 3, 1914.

The Comprehensive Antarctic Expedition,
Academy of Sciences, U. S. S. R.,
Institute of Arctic Geology,
Leningrad.

Received June 21, 1958

THE "HEARTH ZONE" OF THE EARTH'S CRUST, "MAGMATOGENE CROWN," "AREAS OF IGNEOUS ACTIVITY," AND STRUCTURAL ASSOCIATIONS OF INTRUSIONS"[1,2]

by

G. L. Pospelov

This paper presents for discussion some hypothetical considerations on the regional structural units of igneous activity, based on an analysis of well-known facts. In addition, a concept is developed of a "hearth zone" at the base of the earth's crust regulating plutonic and tectonic phenomena.

* * * * *

1. THE EARTH'S CRUST AND ITS "HEARTH ZONE"

The geologic face of the earth bears evidence of its complex history. The structural features at depths inaccessible to direct observation make their presence known through the motley pattern of shallower structures, inasmuch as endogenetic processes of the upper earth's crust are a reflection of deeper processes. A prerequisite for the understanding of the latter is a knowledge of the former.

The concept of the earth's crust is difficult to define in the framework of the overall interior zonation of the earth. One may go so far as to state that the idea of the earth's crust is one of the vaguest concepts in geology. Having originated from an astronomic-geologic premise that the earth is an extinguished star -- a clot of melt covered with a solid slag crust -- this concept has lost its former genetic meaning. Thanks chiefly to the geophysicists' efforts, the continuous subcrustal melt has been done away with.

Seismic evidence indicates that the earth is a solid body, at least as deep as 1000 km [7, 11], and that it has a layered structure. The principal, best expressed, boundaries separating different elastic properties have been interpreted as a boundary of the crust and the outer boundary of the core, with the "mantle" or "subcrustal substratum" in between [11]. The lower surface of the earth's crust, the so-called Mohorovicic discontinuity, has gained a wide recognition, preferred by many to other boundaries, specifically because "it is readily recognized, in many places" [2]. However, although the Mohorovicic discontinuity is observed under the continents nearly everywhere at depths of 25 to 80 km, in oceanic provinces it is locally just beneath the sea bottom as indicated in many areas by the velocity of seismic waves only changing uniformly with depth [11].

Thus, the "crust," as an outer solid zone of the earth, consistently limited below by a continuous and distinct dividing surface, is simply not there. Moreover, the Mohorovicic discontinuity, although a major boundary, is by no means the only one. There are other dividing surfaces, particularly used in a two-later structure concept of the crust. In this chemical and petrologic hypothetical interpretation, the earth's crust (sial) consists of a granite and a basalt layer resting on a peridotite substratum or "mantle" (sima). The latter, in the concept of many geologists and geophysicists, begins almost at the ocean bottom, at least in the Pacific. As a result, that which is called the earth's crust proper and is characterized by a definite chemical and petrologic composition (sial, the granite-basalt layer), has no universal development.

In addition to the hypothesis of a change in the chemical composition at the diverse boundaries in the earth, the presence of phase transitions of various kinds has been postulated. It is very probable, for instance, as V. F. Bonchkovskiy emphasizes, that the crust differs from the subcrustal substance in the same way as a solid crystalline body

[1] Ob "ochagovay zone" zemnoy kory, "magmatogennoy korone "zemli," "arealakh magmatizma" i "strukturnykh assotsiatsiyakh intrusivov."

[2] The author's highly original ideas on the deep-seated geology of the earth's crust are purely hypothetical and require further study of the natural phenomena bearing on this complex problem. Russian Editor.

differs from a solid amorphous one [4]. However, inasmuch as it is contingent on pressure, and consequently on depth, this definition does not quite coincide with the concept of the earth's crust as a layer above the Mohorovicic discontinuity. Many geophysicists believe that this transition begins at depths of about 80 km, where a drop in the velocity of seismic waves is observed, and continues to a depth of 200 m [11].

The concepts of a chemical stratification of the earth are opposed by those of its chemical homogeneity, best substantiated by V.N. Lodochnikov. He regarded the change in the aggregate state of the chemically homogeneous earth-substance as a basis for its internal stratification [10].

Many students abandon altogether the idea of an earth's crust as a layer with a composition of its own, and differing sharply from the other geospheres. They substitute other definitions, such as the isostatic compensation layer, 100 km deep [5, 11]. W. Bucher goes as far as proposing to change the term "crust" to "stereosphere," meaning a hard shell above the "asthenosphere," the plastic layer of Barrell [as cited in 5]. Some geologists designate as the crust a 100-km-thick layer below which the temperature exceeds the melting point for all rocks, at a pressure of one atmosphere [1, see note, p. 52]. This is a departure from the interpretation of the earth's crust as one with zones separated by dividing surfaces, and toward its study with reference to depth changes using such physical parameters as temperature and pressure.

Such premises introduce a new principle into the solution of the problem of the earth's zonation. A.F. Kapustinskiy advanced the theory [7] of a three-layer model of the earth, on the basis of data on the metallization of various substances at superhigh pressures, and of the "degeneration," under these conditions, of the chemical properties of atoms which lose their electronic structure. According to this model, the earth consists of a centrosphere -- a "metallized core of zero chemism;" an intermediate eclogite "intersphere" of "degenerated chemism;" and a "perisphere," a zone of "normal chemism." The concept of the "perisphere," according to Kapustinskiy, corresponds closely to the former idea of the lithosphere or the earth's crust. The boundaries of the perisphere are rather vague, and its thickness is taken to be 50 to 100 km. All of the known chemical reactions, proceeding according to the Mendeleyev periodical law, take place in the perisphere which essentially is a solid crystalline outer shell [7].

It is clear, then, that there is no firmly established concept of the earth's crust. No boundaries have been determined where the most important properties of the terrestrial substance do radically change. Different properties of the upper zones change at different levels, and the concrete meaning of the term, crust, changes depending on what property has been taken as a criterion of the definition. In addition, all of the above definitions are essentially based on the chemical and physical properties and states of the terrestrial substance, whereas even textbooks and manuals have little to say on the geologic meaning of the term, "earth's crust."

In the meantime, a number of basic premises for a broad geologic understanding of the crust has been emerging from the modern study of the physics and geology of the earth. They are inherent in our knowledge of tectonic movements, which is the subject matter of geology.

Perceptible geologic movements are known from the first thousand kilometers below the surface. Deep-focus earthquakes occur at 700 to 800 km. Subcrustal currents, related to the differences in temperatures and pressure, and the differentiation of matter at depth, and involving most if not all of the mantle, have long been recognized as an important phase of deep-seated movements. Many geotectonic hypotheses accept the subcrustal currents and the displacement of matter as a basis of the development of the earth (E. Kraus, G. Haarman, A. Holmes, R.V. Bemmelen, R. Staub, etc). The development of the idea that the deep-seated differentiation of matter was induced and regulated by thermal radiogenic fluctuations (B. and R. Willis, [17]; V.V. Belousov, [1]; etc) has stimulated the theoretical speculations on the leading part of deep stratification and movement in the formation and transformations of the earth's crust. In many modern hypotheses [V.V. Belousov, [1]; P.N. Kropotkin, [9]; V.I. Popov, [13]; V.A. Magnitskiy, [11]; etc.], the problems of magmatism and of the origin of the sial layer are united in a single problem of a radial differentiation of the solid crust. This differentiation occurs in the phase and chemical transformation of the substratum, regulated by radiogenic heat, with the newly formed magmatic bodies rising by buoyancy or else by way of superdeep faults [P.N. Kropotkin, A.V. Peyve, and others].

In all these hypotheses which recognize some movement in a thick layer within the earth, the crust itself figures as an inert formation with respect to the subcrustal body and undergoes only those changes which are induced by the mantle processes. If all this 1000 km-thick layer is a "dynamosphere" of the earth, its uppermost part is the most mobile one, a sort of "dynamosphere of contrasts." Various subcrustal movements

esist the movements of the crust, even as ixed diffuse movements resist the finely lifferentiated, commonly localized, movements esponsible for an amazingly diversified and omplex geologic performance.

It may be stated that the intensified differ- ntiation of geologic movements -- both in ariety and the distribution -- is what deter- nines, to a considerable extent, the typical eologic properties of the crust as an upper enetic zone of the earth. Figuratively speak- ng, the crust is the "boiling" zone of the novements whose supreme expression is gneous activity. Consequently, zones most liversified in their properties, thickness, etc. re located in the earth's crust, as contrasted o the incomparable more homogeneous mate- ial of its mantle. The crust is a locus of nost diverse chemical and phase transforma- ions of matter, as against the lesser, "de- enerating" [7] chemism of the deeper zones. n the final count, the crust is the place vhere the transformation of all kinds of eologic energy passes through its final tages. It is the main arena where the intra- errestrial meets the cosmic energy which ffects the geologic development of the earth.)n the basis of all these properties, the ower boundary of the crust,[3] geologically peaking, should be drawn at the zone of the nitiation of localized and contrasting geologic novements, including the differential "germi- ation" of the tectonic and plutonic processes nd their growth toward the surface.

Many geologists, geophysicists, and geo- hemists agree, on different premises, on an pproximately 100 km-deep boundary, as one f the most important markers, which defines he base of the most active zone of the earth. This is the isostatic compensation level, an pproximate line between the crystalline and morphous states of the earth substance, a ower boundary of the "standard chemism" of ..F. Kapustinskiy; the boundary of the deep- eated differentiation of the earth, according o V.V. Belousov, where it is the most active, nd which determines, specifically, the main eatures of geosynclinal development [1].

However, it should be considered, in stablishing the lower boundary of the crust t the zone of detailed and contrasting geo- ogic movements, that the latter are of a roup character and are marked by a certain eriodicity and even by a finely differentiated hythm. This is suggested, specifically, by he group character of the manifestations of the tectonic and magmatic movements, their regular periodicity and intensity, often strikingly synchronous over large distances, especially clearly demonstrated in the development of igneous complexes at stratigraphic unconformities. This is also attested by the close, many-sided and region-wide relationship of tectonic and plutonic processes. All these phenomena, which develop on the background of irregular geologic movements, or of movements recurring at long and indefinite periods, have been empirically established in the course of numerous geologic investigations in various parts of the globe. They point to a causal relationship, not only between tectonics and magmatism, but of both to some other factors.

The periodicity of geologic processes has long been a difficulty in the application of most of the earlier geotectonic hypotheses. This difficulty was eliminated to a certain extent with the introduction of a radiogenic regulator of the differentiation processes in the terrestrial substance. This, however, achieved a measure of success in explaining only the longest periodicity of the geologic movements, whereas the phenomenon of a more detailed and localized differentiation remains without a satisfactory explanation.

It should be noted, in this connection, that the concept of a primary radiogenic geologic regulator is only a hypothesis postulating a certain continuity of the transfer of geologic movements and energy from the mantle to the crust. Another solution to the problem of the periodicity of geologic movements in the crust is conceivable, if we postulate certain condensers along the migration path of the geologic energy from the depths to the crust -- the condensers capable of storing and periodically discharging this energy -- with the emergence of a rhythm in an originally nonrhythmic flux of matter and energy. Such "regulators" may be of various types and magnitudes. For instance, a mere fracture is capable, by virtue of physical laws, of concentrating the prevailing uniform mechanical stresses and of bringing them to the critical value and to a local periodical discharge (the growth of the fracture), before any deformation takes place elsewhere. Many such "regulators" and "condensers" of geologic energy probably are present in the crust. We believe this to be a problem worthy of attention.

There are reasons to believe (as will be explained below) that the zone of the initiation of the detailed and contrasting differentiation of the geologic movements characteristic of the crust, is a single vast regulator and condenser of the geologic energy. It may be conceived as a zone of development of near-critical energy and physical and chemical

[3]The term, "earth's crust," is unfortunate in the pinion of many. It is one of those terms sanctified y tradition and changing in meaning with scientific levelopments. It should be retained, therefore, only s one which has been developed on a geologic basis.

states of matter, which affords a periodical accumulation and realization of the geologic energy, in processes effective over long distances, acting either slowly or rapidly. Such processes include hydraulic pressure, chain reaction, or the distribution of electric charges throughout the lining of a condenser. Under definite conditions, this zone becomes an area of periodically and rhythmically active tectonic and magmatic hearths, closely depending on each other and on the state of the entire system, as indeed seems to be the case, judging from well-known data. So understood, this hypothetical zone of the earth's crust is a geologic-genetic "hearth" zone. More specifically, it is the zone of the preferential generation of that strictly localized and contrasting magmatogene mobility of the crust material which leads to the formation of the pulsating magmatic centers generating the magmatic melts and highly active magmatogene solutions capable of "energizing" to a high igneous activity fairly large blocks in higher layers. This "hearth zone" is not responsible for the generation of all of the localized and contrasting magmatic and tectonic movements, nor is it a mandatory intermediate condenser of all geologic energy and movements proceeding from the interior of the earth. It apparently does determine, however, the main features of the crust as a region of geologic movements, finely differentiated in space and time.

No attempt is made, in this paper, to interpret the physics of this hypothetical "hearth zone" of the crust and of the processes in it. Nor is there any attempt at the determination of the energy and the movement of matter participating in its development. The physical arsenal at the disposal of geology, for this purpose, is rather poor, in striking contrast to modern achievements in physics. Any further major achievements of the endogenetic geology are not likely to result from mere interminable reshuffling of the same collection of tools. It is also probable that the analysis of the physical nature of such a hearth zone will include such topics as the effect on it of the fluctuation of the magmatic field, as affected by the physics of the earth's core and by cosmic influences which being to attract more and more attention in certain hypotheses presented to explain the geologic development of the earth.

We shall note here some of the evidence of the probability of a zone at the base of the crust: a zone with peculiar properties and peculiar geologic activity.

According to V.A. Magnitskiy [11], a depth of 60 km may be accepted as the lower limit of normal earthquakes. An analysis of the relations of earthquakes and other phenomena shows that volcanism, the younger folded belts, and intermediate shocks are all induced by a primary process occurring at depths corresponding to those of the foci of intermediate earthquakes [11]. The studies of Ye.A. Rozova in central Asia [16], along with some other work elsewhere, show that there is a layer with peculiar properties, at a depth of 60 to 80 km, where the earthquake foci are nearly lacking. Its top -- and the bottom, according to Ye.A. Rozova -- are defined by focal surfaces with a concentration of the earthquake centers. This is especially true for a depth of 60 km [11, 16]. These focal surfaces behave like a dual mobile "lining" of the 20-km-wide aseismic zone.

A.P. Karev [8] cites some interesting data on the electric properties of the terrestrial zones. It was noted in the process of electric survey with a wide spread, that the effective resistance decreased considerably, at a depth of a few tens of kilometers, for reasons which could not be determined. This and some other facts lead to a belief that, at a depth of several tens of kilometers under the continent, there is the upper boundary of a zone which presumably may be interpreted as the upper boundary of the "hearth zone" of the crust. It is possible that such phenomena as the "Mohorovic discontinuity" and some divisions of the second order are related in some way to the existence of this zone. It apparently has no permanent thickness, at any place, but rather fluctuates radially. It may have a layer structure, complicated on top by protuberances which change in size and shape in the course of geologic history, and migrate both radially and laterally. It is also probable that the structural features and the physical properties of this zone are different in the continental and oceanic provinces and under platforms and geosynclines. It is not an accident that seismic study has revealed a definite, although poorly expressed, lack of uniformity in the fairly homogeneous mantle of the earth, under the continents and oceans [11]. This is even more true for the crust and probably for its hearth zone, and is related, to a considerable extent, to the spatial differentiation of the geologic movements and structures of the crust. Nevertheless, elements of the inherited structures and of the physical state of this zone probably played an important part in the processes of the inheritance of the types of certain geologic movements and of their sites, during the course of geologic history, as well as of the persistence in space and time of certain geochemical features of igneous activity, leading to the formation of various geochemical and petrographic provinces.

Certain prerequisites for a probable existence of a hearth zone, along with some indications of its probable structural features,

re to be found in the analysis of regional tructural units of igneous activity.

2. THE "MAGMATOGENE CROWN OF THE EARTH" AND "AREAS OF IGNEOUS ACTIVITY"

Igneous activity is a process that trancends the geotectonic divisions of the crust. t is developed centrifugally, appearing on everal geotectonic levels, binding them toether with the assistance of tectonic movenents. For this reason, its manifestations in he upper layers, accessible to direct geologic tudy, reflect to a certain extent its activity n layers beyond the scope of such study.

The earth probably is constantly surrounded y a sort of inner halo of assorted active nagmatogene projections within the crust, nd partly rising to its surface. In certain eriods of igneous activity, this "halo" flares orth with a particular intensity. By analogy vith the solor corona, it might be called the terrestrial geologic corona." However, the nodern manifestations of this "terrestrial orona" which reach the surface (modern olcanism) are slight. The "terrestrial orona" is accessible for a geologic study nly in its fossil state. There is abundant vidence of past igneous activity in the earth's rust, in the complicated system of extrusive, gneous-metamorphic, and ore-mineral bodies, ll making up a characteristic geologic formaion which may be called the "magmatogene ossil corona," or simply the "magmatogene rown."

All current igneous processes are developed on the background of this "magmatogene rown," superimposing it on the younger equence, and partly reworking the older equences and increasing their density. The ntire "magmatogene crown," formed during ll of geologic history, is the "magmatogene rown" of the first type. Its intersection with he present surface is established in all igneus manifestations, irrespective of the time nd the character of their formation. This crown" consists of "magmatogene" crowns f the second type, formed in definite major eriods of generally intensified tectonicgneous activity. This differentiation possibly hould be carried further, inasmuch as these eriods include some of the widely developed pochs of igneous activity.

"Magmatogene crowns" of the first, econd, and other types represent the largest tructural geologic units of igneous activity. ccordingly, their comprehensive study should o together with the study of such regional nagmatogene associations as igneous comlexes and formations, petrographic provinces, etc. It is related to the study of regional zonation and of the igneous "mosaic."

Each of the noncontemporaneous "magmatogene crowns" is characterized by a vertical sequence of at least three zones of structural origin: the root, intermediate (or stem), and frontal (upper level of igneous activity). The "frontal zone" of "magmatogene crowns" of the second and subordinate types does not always reach the surface, because of its complex primary level. In addition, it is represented in many places by "magmatogene caps" of pyroclastic and extrusive sequences and accumulations of sills and laccoliths. As a result of tectonic turnover, the zones of structural origin of the "magmatic crowns" of the second and other types are displaced with relation to each other and are denuded to various extents. They also possess some common elements of zonation, inasmuch as the "root" igneous zone reaches into the "hearth zone" of the crust where a complex historic change and historic priority (heritage) of the tectonic-magmatic activity hearths takes place. These hearths are distributed within the range of fluctuations for the "hearth zone" -- the latter apparently being mobile.

The degree of unit for the root zones of noncontemporaneous "magmatogene crowns" of the second type determines their mutual superposition, as well as the widely developed phenomena of the inheritance of material features of igneous activity in different regions ("petrographic provinces"), etc. The occurrence of even slight manifestations of a younger igneous activity (magmatic bodies, endogenetic mineralization) in older igneous areas suggests that each major igneous epoch disturbs more or less the whole "hearth zone" of the crust, or at least its major segments.

The "magmatogene crowns" are more continuous in their root zone and less so in the higher zones, with the degree of discontinuity increasing upward. The intersections of these major prongs of the crowns with the denudation surface present the areas of relative concentration of igneous activity.

Igneous activity is always a composite group process, with its group character revealed both historically (magmatic complexes) and spatially (groups of igneous bodies and hearths).

The regional accumulations of extrusive and meta-igneous bodies, both being the traces of peculiar large "spots" and "bands" of an intensified igneous activity on the face of the earth are the principal regional geostructural elements of the "magmatogene crown." They may be called the "areas of the maximum igneous activity," or simply the "igneous areas."

The conception of these accumulations as important geologic units is relatively old, with interest in it recently revived.

Following the above division of the "magmatogene crown" into the first and second types, the "igneous areas" are subdivided in the same way. "Igneous areas of the first type" are vast provinces of igneous bodies formed in various igneous epochs. Such areas primarily embrace the complex geosynclinal provinces and secondary platforms, as well as certain shields and primary platforms. "Igneous areas of the second type" are the regions of concentration of the manifestations of large igneous epochs, related to the development of major geotectonic units. Inasmuch as such units and epochs are developed in stages, smaller subdivisions are possible for the igneous areas. As a matter of fact, they are being considered in works on the metallogenic provinces by Yu. A. Bilibin and his school [3].

Although associated with major geotectonic units, the igneous areas do not fully coincide with them. They have a degree of independence, apparently because of certain differences in the physical nature of the tectonogene and magmatogene activity of the "hearth zone." However, they are characterized by important features reflecting the evolution of the "hearth zone," its fluctuations and the regional geochemical mosaic of the crust, related to the general history of its development.

The features of the igneous areas are best revealed in intrusions, as a type of igneous activity common for all geotectonic levels. For illustration, there are the igneous areas of the Altay-Sayan province [15].

A regional geotectonic zonation is well demonstrated in the Altay-Sayan province. It is expressed in the east-west change of the ancient Siberian platform, first to the ancient Salairian-Caledonian (Cambrian and Silurian) folded province -- which definitely became a secondary platform at the close of the Caledonian stage -- and then to the Variscan folded province, within the ancient geosyncline, finally to change to a secondary platform, at the end of the Variscanian [Fig. 1]. The area of distribution of the maxima of the Salairian and Caledonian intrusions is associated chiefly with the regions of an early consolidation of the Altay-Sayan geosynclinal province. Some of its prongs, however, encroach upon the zone transitional to the Variscan geosyncline, with widely developed lower Paleozoic sequences, and upon the crystalline fringe of the Siberian platform.

The area of the maximum Variscan intrusions is associated chiefly with the Variscan and a zone transitional to it (Altay). However, it also embraces, to a considerable extent, the provinces of an earlier consolidation of the original geosyncline and partly extends over the crystalline fringe of the Siberian platform. As a result, various igneous areas, with intrusions of different ages, are superimposed upon each other on the present denudation surface.

Each of these igneous areas has a mosaic structure. Included are isolated and superposed developments of different and commonly noncontemporaneous intrusive complexes, evolving from the acid to the basic. In addition, an evolution of the intrusions is fairly well marked within each area, from ultrabasic and basic types to acid. The same direction of evolution of igneous activity is noticeable in the larger stages of its development, which is responsible for the intricate igneous pattern.

Thus, the Salairian-Caledonian igneous area, as a whole, is characterized by a considerable development of basic extrusives. Besides the preponderant granitoids, it contains comparatively many basic and ultrabasic intrusions and granitoid intrusions of a higher basicity or alkalinity, as well as alkaline intrusions. The Variscan igneous area is marked by a wide distribution of essentially acid extrusives and acid granitoids, including the characteristic porphyritic granites. Basic and ultrabasic intrusions here are of less importance. These features also occur in places where the igneous areas are superposed upon each other. Thus, the earlier igneous area appears to be more basic than the later one, developed within the same vast original Proterozoic to lower Paleozoic geosyncline but confined chiefly to the regions of a revived middle Paleozoic geosynclinal development. This appears to be a definite hint at a comparatively close relationship between the nature of the local tectonogene activity of the hearth zone and the position of its generating segments with relation to the granite and basalt geospheres of the earth, which affects the general petrographic features of the igneous activity.

The relation between the degree of activity and the differentiation of geotectonic movements, on one hand, and the petrographic types of igneous activity within definite igneous areas, on the other, is also manifested in the history of the development of such areas. The more quiet initial stages of the geotectonic development of the corresponding geosynclines result in the formation of spilite-keratophyres and of ultrabasic and basic intrusions. The formation of secondary platforms and the development of both the Salairian-Caledonian and the Variscan igneous areas are terminated everywhere by the emergence of final basic

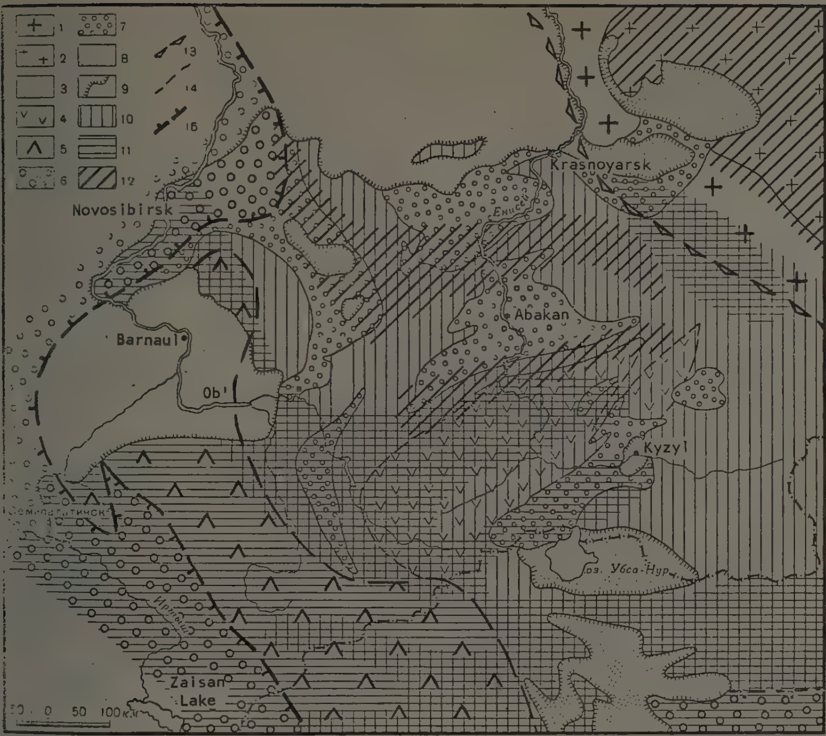


FIGURE 1. Areas of active igneous development in the Altay-Sayan and adjacent provinces.

1 -- Precambrian prong of the Siberian platform; 2 -- the Siberian platform; 3 -- region of the Cambrian and Silurian consolidation of the lower Paleozoic synclinal province (Salairian and Caledonian rocks); 4 -- transition to the Variscan folded zone (Caledonian and Variscan rocks); 5 -- Caledonian folded zone; 6 -- Variscan (Ob'-Zaisan) folded zone (exposed and under an unconsolidated cover); 7 -- Variscan foredeeps and intermontane depressions in Salairian and Caledonian rocks; 8 -- Mesozoic and Cenozoic depressions in Paleozoic sequences; 9 -- boundary of Mesozoic and Cenozoic deposits of the western Siberian plain.

Igneous areas: 10 -- Salairian-Caledonian; 11 -- Variscan; 12 -- Permian, Triassic and Mesozoic (sills, dikes, stocks); 13 -- boundary of the Siberian platform; 14 -- western boundary of Salairian and Caledonian rocks; 15 -- boundary of the Variscan folded zone.

(diabase, etc.) dikes, although unevenly distributed regionally. These dikes mark the transition periods from a folded to a platform state; they complete a full igneous cycle and initiate a new one which comes to fulfillment in a new igneous area.

3. THE STRUCTURAL ASSOCIATIONS OF INTRUSIVES AND THE STRUCTURE OF IGNEOUS AREAS

Igneous areas present definite accumulations and associations of magmatogene formations whose distribution and morphological features make a pattern characteristic of the main features of a given igneous area. Most important are the distribution patterns of intrusive formations.

In most instances, the spatial distribution of the intrusions, as fixed at the present denudation surface, is regular rather than haphazard. As a matter of fact, endogenetic bodies of any size are usually found in groups of definite morphologic features. The latter have been best studied from the grouping of endogenetic ore bodies, deposits, ore nodes,

zones, etc., and to a smaller extent, from the grouping of the intrusives.

The regular spatial outlines of the intrusives may be called their structural associations. Along with the petrographic and stratigraphic associations or assemblages of intrusive bodies, they are important indexes to the patterns of the intrusive igneous activity.

The structural associations of intrusives are diversified. Without going into details, we shall only note that they may be subdivided into two large groups associated with transitions: the linear and the cluster. Each one, in turn, may be subdivided according to structural-density association of low, medium, and high density; the character of the intrusive combinations; their magnitude; etc. For instance, the linear structural intrusive associations may be separated by their structure, into interior unoriented, longitudinal (elongated with the zone), diagonal, transversal, staggered (en echelon), plumate, reticulate, etc. The cluster structural intrusive associations are divisible into irregular clusters -- cluster lenses, cluster blocks, annular clusters, etc.

Naturally, these structural intrusive associations are of various sizes and are very complex. They may be confined to small areas (local associations) and to large regions (regional associations), up to the entire "magmatogene crown" of the earth (planetary associations). The linear associations are commonly crossed and combined with the cluster ones, so that individual intrusives and their associations may participate simultaneously in two or more linear grouping, etc.

As an illustration of the regional structural igneous associations, we present a simplified morphologic map of the Altay-Sayan province, on a 1:2,500,000 geologic map. Figure 2 shows a part of an igneous area of the first type, consisting of several areas of the second type. Intrusives of various ages and compositions are designated with the same symbol. The structural associations of intrusives are marked with dots whose concentration defines some of the outlines of associations of different magnitudes; also some of the intrusive boundaries, considered to be worth emphasizing. Figure 3 does not show the intrusives, and the dots mark the generalized morphology of their structural associations, as one possible interpretation. To be sure, such a map is conditional in many respects, and is open to other interpretations.

A further refinement in the method of making such structural intrusive associations maps will enrich them in historic, geotectonic, and petrogenetic data, and decrease incidental effects and the possibility of an arbitrary interpretation. On the whole, however, this morphologic map gives some idea of the structural intrusive associations in the Altay-Sayan province, at least of their most important elements. The map shows a wide development of the linear structural associations, in intersecting directions, with the plumate types locally similar to the so-called "horse tail," developed in the Kuznetsk Alatau, western Sayan, and eastern Sayan. In addition, a major block structural association is present west of the Altay, with a block-linear internal structure and a triangular outline.

Without analyzing the details of this scheme, we shall note its one important general feature. On one hand, elements of the structural intrusive associations (and the distribution of extrusives, as shown in Fig. 3) display a close relation with such structures as the granites of large geotectonic units, thick zones of folding and deep faulting, steplike flexures along the rims of depressions, major overturned and overthrust folds, etc. On the other hand, they exhibit a degree of independence from those structures, being subject to at least four intersecting structural trends as shown in Figure 2. An illustration of these trends is the Trans-Altay submeridional belt of intrusive concentrations stretching over 500 km in the direction of Stalinsk-Marka Kul' Lake. This belt is a concentration of intrusives of various age and composition, of various geogectonic stages (from Proterozoic to Devonian) and exposed at a different level of mountain relief. It crosses deep faults, depressions, benches, in an unconformable superposition. The same is true for the neighboring eastern submeridional boundary of the western Altay block accumulation of intrusives. Another sublatitudinal belt lies at the latitude of Gorno-Altaisk, trending across the meridional belt, where it connects the Altay front (a marked bench in the relief of tectonic origin) with that of western Sayan.

Excellent fracture-type structures, partly unconformably superimposed upon the standard-type structures and affecting the structural associations of the intrusives and and their morphologic features, are present not only in the Altay-Sayan province but also in neighboring Kazakhstan, and in many other regions. It may be stated that they are present everywhere, to some extent. These "through" structures are a sort of "macroparting" or "geotectonic parting" of the crust. On their background, other structures are developed, of the "geotectonic lattice" type [14]. Their origin is related to a special type of geotectonic compensation of stresses, in macrovolumes.

In agreement with the concepts of stresses

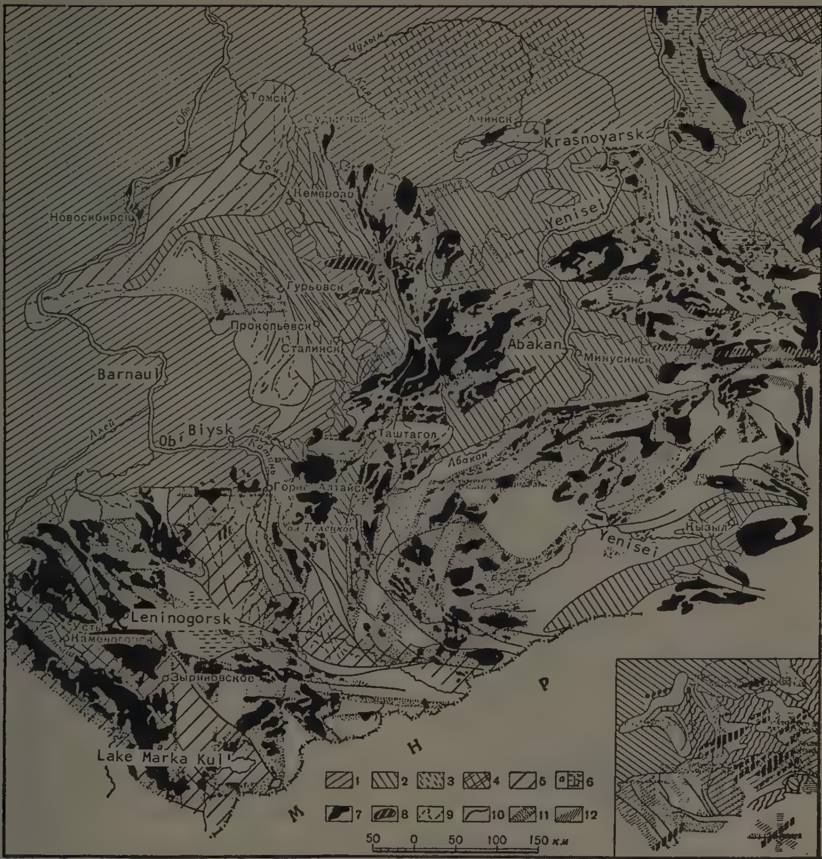


FIGURE 2. Distribution of the intrusives in the Altay-Sayan province (on a 1:2,500,000 geologic base map).

1 -- Mesozoic and Cenozoic of the west-Siberian plain and of the interior depressions in Paleozoic sequences; 2 -- foredeeps and intermontane troughs in the Salairian-Caledonian folded zone (Devonian, Carboniferous, Permian); 3 -- same, under an unconsolidated cover; 4 -- the Siberian platform (Ordovician, Silurian, Devonian); 5 -- the Variscan Ob'Zaisan folded zone, and a province of intermontane troughs and a transitional Altay zone (Devonian, Carboniferous, and windows of Ordovician and Silurian); 6a -- the Salairian-Caledonian folded zone (Proterozoic, Cambrian, Ordovician, Silurian); 6b -- Precambrian crystalline blocks in the Gornyy Altay, eastern Sayan, and Yenisei Range; 7 -- intrusives of various composition and age; 8 -- sills of the "melaphyre horseshoe" of the Kuzbas; 9 -- elements of stratified structures; 10 -- faults; 11 -- elements of the structural intrusive associations and of their internal morphologic features; 12 -- axial zones of the plumate intrusive associations.

In the lower right corner, a general scheme of the distribution of main linear structural intrusive associations.

of the first and second kind prevailing in the modern strength theory the author proposed [14] a hypothesis for the differentiation of geotectonic stresses into two following types: 1) the integrally balanced within the entire body under stress; as a result, this body, despite its heterogeneousness, is deformed as a continuum; 2) the differentially balanced within the confines of individual volumes of the body under stress; as a result, this body

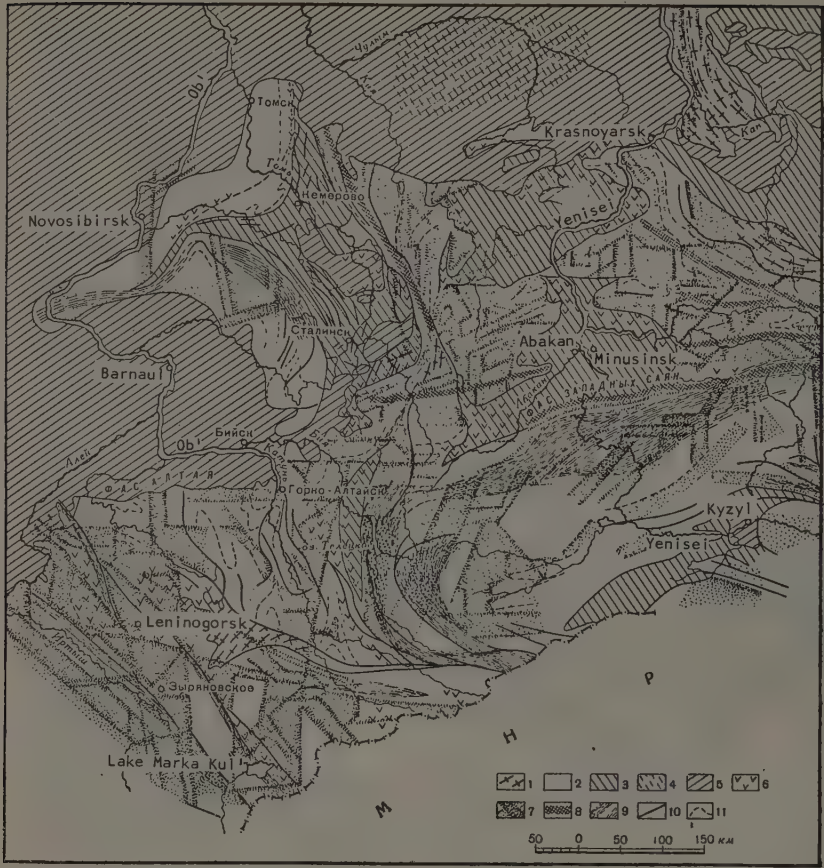


FIGURE 3. Generalized morphologic map of the structural intrusive associations in the Altay-Sayan province.

1 -- windows of crystalline Precambrian; 2 -- Paleozoic of the folded province; 3 -- middle and upper Paleozoic foredeeps and intermontane troughs in Salairian and Caledonian rocks, and the Siberian platform; 4 -- same, under unconsolidated sequences; 5 -- Mesozoic and Cenozoic of the west-Siberian plain and of interior depressions; 6 -- main provinces of Devonian extrusives in the Altay and the Minusinsk depression; 7 -- structural intrusive associations and their morphologic features; 8 -- axial zones of plumate associations; 9 -- zones of intensive folding and metamorphism; 10 -- faults; 11 -- elements of stratified structures.

is deformed differentially, as an anisotropic medium. The stresses of the first type lead to the formations of the "through" structures of a reticulate type, similar to partings; the stresses of the second type result in assorted structures, fitting into each other. Both types are closely related, since they have been formed in the differentiation according to the types of the balancing of common geotectonic stresses.

The formation and distribution of the intrusives is affected chiefly by deep-seated structures. Some of the latter, similar to the so-called deep faults, belong to the "enclosed-linked" type; the others, such as "macropartings," (essentially, also a kind of "deep-seated" faulting), belong to the "geotectonic lattice" type. The first have a more localized development, while the second are regional in scope, expressed with various

degrees of intensity and completion. As a matter of fact, the first type of structures is developed on the background of this "parting," with the reticulate pattern assuming a greater importance in structurally more homogeneous, or rigid, bodies (platforms, shields). This grows in importance downward as well, in the direction of a better integrated balance of mechanical stresses in large volumes. In addition, in concentrating on themselves the geotectonic stresses (following the familiar mechanical laws of the stress concentration at fractures, benches, etc.), these structures are continually rejuvenated, expand laterally, and "grow" at the base as new geotectonic levels. In this respect, "the tectonic inheritance principle" of N.S. Shatskiy and A.V. Peyve [12] is clearly expressed in the development of such structures.

In its capacity as an "open," deeply expanded (intensified downward), and nearly universally developed structure, the geotectonic fracture lattice exercises a decisive influence on the structural associations of the intrusives whose mutual position is commonly unaffected by the clearly expressed fracture structures which are in the same relation to the macroparting as the local disjunctions are to the fracture lattice of the standard parting. The geotectonic fracture lattice probably affects in the same way the bedding intrusions of a trap type, characteristic of platforms, inasmuch as the fracture lattices -- as long since noted by N.S. Shatskiy -- belong to the most common regional types of platform structures. Of course, a separation of structural associations of bedding intrusions, with their outlines on the denudation surface strongly conditioned by the relief and the degree of erosion, is rather difficult. It requires a special study. However, certain minor regularities can be approximately outlined, at least to a small extent. This is shown on a map, Figure 4, compiled from the geologic and geotectonic maps of the Siberian platform, scale 1:5,000,000, 1956. It presents one of the variants of our generalized and very approximate morphologic outlines of the structural associations of trap intrusions. According to it, the main regional annular association, which embraces a considerable part of the platform and is associated with its principal structures, breaks up into a system of subordinate regional associations. The block-linear types apparently are widely developed, along with elements of the rhythmic distribution of trap accumulations and with numerous oval and annular-cluster trap bodies.

The inherent fundamental features of the "open" fracture structures, expressed in their recurrent rejuvenation and the growth of their elements, definitely affect the inherent structure of the corresponding, mutually superimposed structural intrusive associations of igneous areas of the second type. In the development of new igneous areas, the old associations are "extended" and "packed" in addition to the formation of new ones. Consequently, the individual cluster or linear intrusive groupings, such as of the Altay-Sayan province, consist locally of intrusions of different igneous cycles, appearing to grow on each other. As a result, even such historically and structurally complex terrains as the Altay-Sayan province, with several superposed igneous areas of the second type (Fig. 1), show elements common to all structural intrusive associations which characterize, as a whole, the details of the igneous area of the first types (Figs. 2 and 3).

The effect of the "open" deep-seated fracture structure on the regional structural intrusive associations is not limited to their role as the path of migration and as structural localizers. Insofar as these fracture structures, having originated according to mechanical laws, do regulate and concentrate the mechanical stresses of either sign, the regions of their distribution are those of special physical and physical chemical conditions.

Mechanical stresses affect the course of physical chemical processes. It may be assumed therefore that such stresses in the root parts of deep-seated structures, especially in a geotectonic-fracture lattice and in deep faults, affect the physical chemical state of the hearth zone of the crust and the distribution and partly the emergence in it of magmatically active centers. A similar concept, somewhat modified, has been advanced by M.A. Usov, P.N. Kropotkin, and others. Such conditions make for some unity in the distribution of both the deep-seated migration paths of the magmatic material and of the magmatically active segments of the hearth zone. They also make up a sort of "tectonic-igneous machine." This unity of action affects the perpetuation of both the foundation of active hearths and the structural associations of intrusives belonging to various igneous areas.

It follows, that the character of the distribution of magmatogene formations within the igneous areas, reflects not only the distribution of the migration paths and structural localizers affecting them, but also the position of magmatically active segments of the hearth zone, as the specific features of the internal structure of the latter.

It appears that the more regional and more consolidated the structural intrusive associations are, the better they reflect the structure of the hearth zone, the mosaic of its physical chemical states, its internal spatial differentiation, and the level of its

FIGURE 4. Generalized morphologic map of the structural associations of trap intrusions in the Siberian platform. Probable structural intrusive associations and their morphologic features are designated by dots.

Provinces: 1 -- Mesozoic and Cenozoic of west-Siberian plain; 2 -- Jurassic and Cretaceous; 3 -- Triassic and Permian; 4 -- Ordovician and Silurian; 5 -- Cambrian; 6 -- Archaean, Proterozoic, and Proterozoic to Cambrian; 7 -- Angara-Lena foredeep; 8 -- Paleozoic Ural-Siberian folded province; 9 -- boundary of Permian and Triassic deposits (main platform structure type); 10 -- boundaries of deposits of various ages; 12 -- boundary of the Angara-Lena foredeep; 13 -- western boundary of the Siberian platform; 14 -- boundary of the unconsolidated cover of west-Siberian plain.

boundaries. Such differentiation emerges at times in the form of regional structural intrusive associations, characteristic of definite petrographic types of the intrusives. For instance, the Altay-Sayan province contains several major intersecting wide "open" linear associations of ultrabasic, basic, and alkaline intrusives, of different ages, from the lower to upper Paleozoic and Mesozoic. Related to these belts of intrusive concentrations -- hundreds of kilometers long and cutting many major structures -- are zones of endogenetic iron and other ores of various ages [15].

It appears that certain local boundaries of cluster intrusives and the occurrences of principal endogenetic deposits along the periphery of major structural intrusive associations, as is the case of some regions of the Altay-Sayan province [15], should be associated with this mosaic -- verging on a geometric plan -- of the hearth zone structure. These phenomena characterize the physical chemical zonation in the cluster accumulations of magmatically active hearths and the concentration of ore-forming processes common on the periphery of the hearth clusters. All this opens new possibilities for a comprehensive regional structural-petrographic-metallogenic analysis supported by the analysis of regional igneous units.

REFERENCES

1. Belousov, V,V., OSNOVNYY VOPROSY GEOTEKTONIKI [MAIN PROBLEMS IN GEOTECTONICS]: Gos. Geol. Izd. 1954.

2. Berg, F., FIZIKA ZEMNOY KORY [PHYSICS OF THE EARTH'S CRUST]: Izd. inostr. lit., 1957.

3. Bilibin, Yu.A., METALLOGENICHESKIYE PROVINTSII I METALLOGENICHESKIYE EPOKHI [METALLOGENIC PROVINCES AND EPOCHS]: Gos. Geol. Izd., 1955.

4. Bonchkovskiy, V.F., VNUTRENNEYE STROYENIYE ZEMLI [INTERNAL STRUCTURE OF THE EARTH]: Akademiya Nauk SSSR, Izd., 1953.

5. Bucher, W., DEFORMATSIYA V OROGENICHESKIKH POYASAKH [DEFORMATION IN OROGENIC BELTS]: Sborn. Zemnaya Izd. Inostr. lit., 1957.

6. Gutenberg, V., STROYENIYE ZEMLI [THE STRUCTURE OF THE EARTH]: Ob"yed. nauch.-tekn. izd., 1935.

7. Kapustinskiy, A.F., K TEORII ZEMLI [THEORY OF THE EARTH]: Sborn. Vopr. geokhimii i mineralogii. Akademiya Nauk SSSR, Izd., 1956.

8. Karev, A.P., OSNOVY GEOELECTRIKI [PRINCIPLES OF GEOELECTRICS]: Part I. Gos. Tekh. Izd., 1951.

9. Kropotkin, P.N., SOVREMENNYYE GEOFIZICHESKIYE DANNYYE O STROYENII ZEMLI I PROBLEMA PROISKHOZHDENIYA BAZAL'TOVOY I GRANITNOY MAGM. [MODERN GEOPHYSICAL DATA ON THE STRUCTURE OF THE EARTH AND THE PROBLEM OF THE ORIGIN OF BASALT AND GRANITE MAGMAS]: Akademiya Nauk SSSR, Izv., Ser. Geol., no. 1, 1953.

10. Lodochnikov, V.N., NEKOTORYYE OBSHCHIYE VOPROSY, SVYAZANNYYE S MAGMOY, DAYUSHCHEY BAZAL'TOVYYE PORODY [SOME GENERAL PROBLEMS ASSOCIATED WITH MAGMA-PRODUCING BASALT ROCKS]: Vseross. mineralog. ob., Zapiski, ser. II, ch. 68, vyp. 2 and 3, 1939.

11. Magnitskiy, V.A., OSNOVY FIZII ZEMLI [PRINCIPLES OF THE PHYSICS OF THE EARTH]: Gos. Geodez. Izd., 1953.

12. Peyve, A.V., PRINTSIP UNASLEDOVANNOSTI V TEKTONIKE [THE INHERITANCE PRINCIPLE IN GEOTECTONICS]: Akademiya Nauk SSSR, Izv., Ser. Geol., no. 6, 1956.

13. Popov, V.I., NEKOTORYYE OSNOVNYYE POLOZHENIYA YADRENOY TEORII RAZVITIYA ZEMNOI KORY [SOME BASIC PREMISES OF THE CORE THEORY OF THE DEVELOPMENT OF THE EARTH'S CRUST]: Uzb. otd. Vses. mineralgo. ob., Zapiski, vyp. 7, 1955.

14. Pospelov, G.L., O TIPAKH MEKHANICHESKIKH GEOLOGICHASKIKH NAPRYAZHENIY I GEOTEKTONICHESKOY RESHETKE [TYPES OF MECHANICAL GEOTECTONIC STRESSES AND THE GEOTECTONIC LATTICE]: Vost. fil. Akademiya Nauk SSSR, Izv., no. 1, 1957.

15. ___________, STRUCTURNO-GEOLOGICHESKIYE ZAKONOMERNOSTI RAZMESHCHENIYA ZHELEZO-RUDNYKH RAYONOV ALTAYE-SAYANSKOY OBLASTY [STRUCTURAL-GEOLOGIC PATTERNS IN THE DISTRIBUTION OF ALTAY-SAYAN IRON ORE REGIONS]: Ibid, no. 3, 1957.

16. Rozova, Ye.A., STROYENIYE ZEMNOY KORY V SREDNEY AZII [THE STRUCTURE OF THE EARTH'S CRUST IN CENTRAL ASIA]: Seism. Inst. Akademiya Nauk SSSR, Trudy, no. 94, 1939.

17. Willis, B, and R. Willis, ERUPTIVITY AND MOUNTAIN BUILDING: Bull. Geol. Soc. Am., v. 52, no. 10, 1941.

Institute of Geology and Geophysics,
Siberian Division
of the Academy of Sciences, U.S.S.R.
Novosibirsk

Received July 29, 1957

THE TECTONIC HISTORY OF WESTERN UKRAINE IN CONNECTION WITH A TECTONIC DIFFERENTIATION OF THAT PROVINCE[1]

by

V. I. Slavin

Western Ukraine contains regions with diversified structural features and with a varied history of tectonic development. Its tectonic differentiation can be worked out only with painstaking analysis of its structural history, including its initiation and subsequent development, and its morphologic features.

Several attempts have been made at a regional tectonic differentiation of parts of western Ukraine: on the platform, by W. Teisseyre [15], M. M. Tetyayev [16], V. D. Laskarev [6], W. Zych [18], D. N. Sobolev [10]; in the Carpathians, by V. Uhlig [17], Ya. Novak [13], G. Svidzinskiy (1934), K. Tolvinskiy (1927). In recent years, outlines of the tectonic differentiation of the Carpathians have been proposed in papers of M. V. Muratov [7], V. I. Slavin [9], T. Szalai [14], A. A. Bogdanov [2], O. S. Vyalov [4], and V. G. Bondarchuk [3].

The recent tectonic differentiation of the platform was presented initially in a paper by N. S. Shatskiy in 1946 [12]. Subsequently this problem was considered by G. Kh. Dikenshtein [5], D. P. Naydin [8], and by others.

Most of the earlier works took the morphologic differences in the structural forms of various zones for the basis of the tectonic differentiation. Although some very interesting structural features were revealed by this study, no valid tectonic determination for any zone was possible without a profound analysis of its tectonic history.

The division of the western Ukrainian province into two main regions, different in their structure -- the Russian platform in the north and the most ancient geosyncline in the south -- took place in pre-Rhiphean time.

The then young Russian platform underwent intensive downwarping in its western and southwestern part, with the formation of Rhiphean-Cambrian and Ordovician terrigenous deposits whose structure was unraveled by P. L. Shul'ga [11] and others. These deposits were more than 1,000 m thick. This was the beginning of the western platform-edge depression.

At this time, the Ukrainian crystalline shield emerged as an uplifted structure. The union of the two structures was achieved by means of a flexure, passing at depth to faults. The latter have been noted along the Goryn', Korchin, and Sluch Rivers. These faults were associated with mighty flows of basic lava near the villages of Berestovets, Yanova Dolina, and elsewhere.

Cambrian and Ordovician deposits, also represented chiefly by terrigenous-clastic material of a platform type, are readily correlative with the synchronous Baltic area deposits. In Moldavia, on the southern slope of the Ukrainian crystalline massif, an edge syneclise was formed, with sediments of the platform type, as much as several hundred meters thick.

The ancient Paleozoic history of the present Carpathian area was quite different. Here, intensive geosynclinal downwarps originated in the lower Paleozoic, with the accumulation of thick arenaceous argillaceous, perhaps flyschlike, deposits taking place, along with extrusive activity and the outpouring of chiefly basic lavas. Such are the Marmarosh area lower-metamorphic schists and gneisses with amphibolites.

The Caledonian folding originated in the interior Carpathian zones, as indicated by the stratigraphic break and angular unconformity between the lower metamorphics and the Devonian in the Marmarosh and Spiss-Hemer Mountains. The folding was accompanied by an injection of granitoids, in some inner Carpathian areas. The exact location of the Russian platform-folded province boundary cannot be as yet determined, since it has

[1] O tektonicheskoy istorii zapadnoy Ukrainy v svyazi s tektonicheskim rayonirovaniyem etoy territorii.

been covered everywhere by younger downwarps and even by Hercynian and Alpine folded structures. The presence of a dipping and fairly strongly consolidated Upper Silurian (Chertkov bed) directly below the Jurassic in a Rava-Russka bed borehole is not an evidence of contemporaneous movements. The presence of equally well-consolidated Carboniferous metamorphics in boreholes neighboring the Rava-Russka (such as at Ugnev) and the absence of a Paleozoic break above the Chertkov bed, in the Dniester area, do not favor the hypothesis of a wide Caledonian development in the north. In any event, it is impossible to separate Caledonian structures of the western provinces of the Ukrainian S. S. R. or Moldavia, on a tectonic map.

The development of an upper Paleozoic geosyncline began in the Carpathians with intensive downwarps. According to V. S. Sosinovich, the Devonian and Carboniferous in the Rachov massif is as much as 5,000 m thick. The upper Paleozoic is represented here by mica-chlorite, sericite, and graphite schists interbedded with quartzites. Limestones and marbles occur in the lower part of the section.

A correlation of this section with those of the same zone in Slovakia and Romania discloses that the Devonian thickness is more consistent than the Carboniferous, and that upper Carboniferous and Permian deposits are commonly represented by continental facies or are altogether missing.

Numerous intrusions occurred at the close of the Paleozoic, both acid and basic; especially large granite batholiths occur in the Tatry and Marmarosh areas. Paleozoic rocks here have been strongly metamorphosed. All this leaves no doubt as to the perfectly normal development of the upper Paleozoic geosyncline, with its marked downwarping in the Devonian and lower Carboniferous; with middle and upper Carboniferous differential movements and igneous activity; and with a well-defined Hercynian folding, possibly consisting of two phases: the Carboniferous and Permian.

As shown in Fig. 3, this Hercynian geosynclinal zone is traceable along the tectonic zone of the main anticlinorium, extending somewhat beyond it in the north. It is of interest that such a well-defined zone of folding was not accompanied by the formation of a definite foredeep. This is probably the result of a high position of the southwestern edge of the Russian platform, at the end of the Carboniferous, Permian and Triassic, and to the lack of major uplifts along the geosynclinal rim.

At the same time, the southwestern part of the Russian platform reacted very sharply to the movements in the Hercynian geosyncline. In the Upper Silurian, it was entirely covered by sea, with the ceposition of fairly thick carbonate oozes. The subsidence continued into the Devonian, although at a slower rate. For this reason, by Lower Devonian, marine conditions gave place to lagoonal-continental. In the Carboniferous (perhaps the end of the Devonian), the oscillatory movements in the platform province underwent a transition. The eastern part of Podolia, along with the Ukrainian shield and the Moldavian segment of the platform, were uplifted while the western part went down as an incipient edge syneclise of the Russian platform -- the Lvov trough. In the north, the eastern limb of the latter bordered on the Brest-Kovelskiy prong of the Belorussian massif which had been in the process of uplifting, since the close of the Silurian [5]. The differential movements of the Lvov trough and the Brest-Kovelskiy prong led to the formation, in the lower Carboniferous, of a major fault trending nearly latitudinally, with a throw of about 1,300 m (P. L. Shul'ga).

Such is the upper Paleozoic history of the southwestern part of the Russian platform and of the typical Hercynids of the inner Carpathian zones. This review would not be complete without a description of the outer Carpathian development, a zone little known but important for an understanding of the final stage of Hercynian history.

Between the Hercynids of the inner Carpathian zones and those of the Russian platform, there lies a province whose structure can be only inferred from the uplifted parts of its basement in the Dobrudja and the Swietokrzyskie Mountains; also from the pebbles and blocks in the younger deposits along the outer Carpathian arc. Limestones and marls were deposited there, during the upper Paleozoic, along with clastic rocks: sandstones, conglomerates, and shales. These deposits are 1,000 to 2,000 m thick, although appearing to be considerably thinner than those of the inner zone.

It should be noted that, in contrast to the inner zone, Permian and especially Triassic deposits are widely developed here. On the Zmeinyy (Snake) Island, they are represented by motley mudstones, sandstones, and conglomerates, more than 1,500 m thick, carrying plant imprints. The northern Dobrudja Carboniferous and Permian are represented by a flyschlike volcanic formation, "karapelite;" the Lower Triassic, by motley rocks; Middle Triassic, by limestones intercalated with porphyrites, quartz porphyries, etc.; Upper Triassic, by limestones, shales, and sandstones. The Triassic is more than 1,000 m thick. Upper Paleozoic and Triassic deposits were cut by large intrusions of microcline-

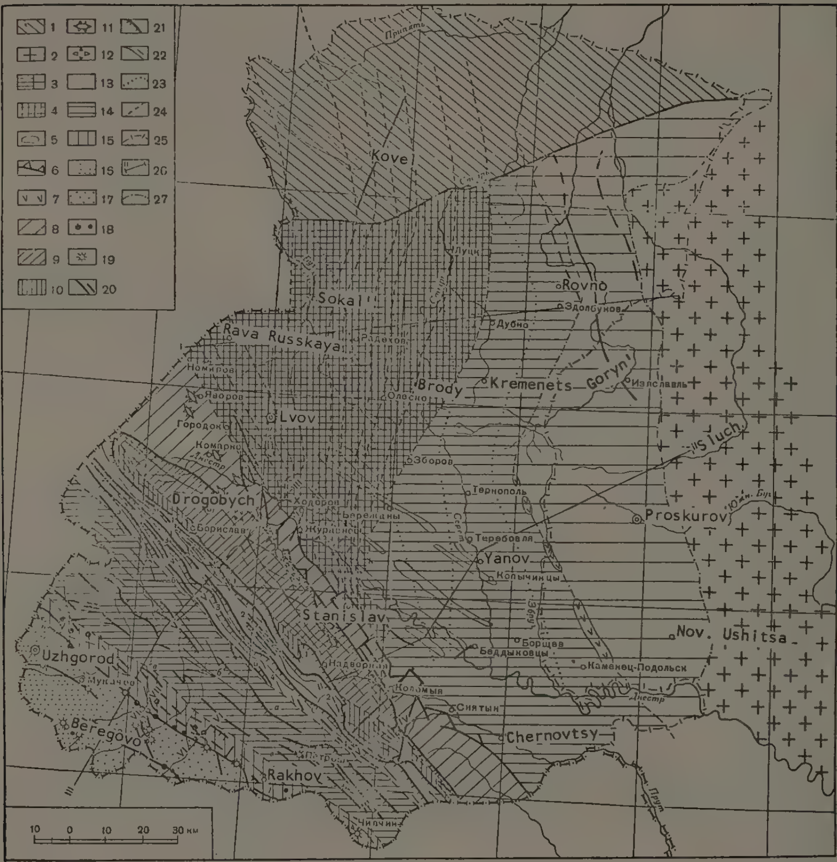


FIGURE 1. Generalized tectonic map of the western province of the Ukr.S.S.R.

I. Russian platform: 1 -- Belorussian massif; 2 -- Ukrainian shield; 3 -- zone of the inner and outer slopes of the shield; 4 -- Lvov Mesozoic depression; 5 -- platform folds; 6 -- flexures; 7 -- "toltry" (limestone hills).

II. Carpathian foredeep: 8 -- outer limb zone; 9 -- central zone; 10 -- inner limb zone; 11 -- brachyanticlines of the outer limb; 12 -- brachyanticlines covered by overthrust.

III. Carpathian folded province: 13 -- outer anticlinorium zone; 14 -- central Carpathian structural zone, with subzones: a) Central syncline; b) Gorgan-Petrosh; c) Poloninskaya; 15 -- Main anticlinorium zone.

IV: Transcarpathian Miocene trough: 16 -- Chopmukachev segment; 17 -- Upper Tissa segment; 18 -- minor intrusions; 19 -- assumed volcanic centers; 20 -- normal faults; 21 -- thrust faults; 22 -- anticlinal axes; 23 -- contours on Precambrian crystallines; 24 -- contours on the Cretaceous; 25 -- boundary of western provinces; 26 -- cross-section lines; 27 -- zone boundaries. Figures designate subzones of outer anticlinorium; 1 -- Beregovaya; 2 -- Orovskaya; 3 -- Skol'skaya; 4 -- Parashka; 5 -- Zelemyanka.

biotite granites, amphibolites, and gabbros, fairly strongly metamorphosed and folded.

In the Carpathian foothills, pebbles of Cretaceous, Paleogene, and Neogene conglomerates carry verrucano-type conglomerates, dolomites similar to those from the vicinity of Ismail [4-a], and apparently Triassic limestones.

Large blocks of speckled gray to black bituminous limestones have been observed in the vicinity of Przemysl. In their fauna, they belong to the Devonian and Carboniferous facies similar to those from the Cracow area.

Thus, a Paleozoic and Triassic sedimentation took place in the outer Carpathian zone and in the Dobrudja, the Triassic sedimentation being particularly intensive. The entire province was folded at the close of the Triassic, apparently into straight linear, northwesternly trending flexures. The time of this folding was pinpointed in the most recent work of I. Znosro (1952) who showed that the Rhaetian of the Swietokreyskie Mountains rested with an angular unconformity on eroded Keuper motley mudstones. These mudstones, carrying intercalations of the Lisovsk breccia, dip at angles as much as 23°, whereas the Rhaetian-Liassic (Lisetsk beds) is undisturbed.

After the folding, the entire outer Hercynid zone underwent a crestal uplift, with the maximum intensity in the northern Dobrudja. A foredeep was formed along the rising Hercynids, presently traceable northwest of the Black Sea to the western border of the U. S. S. R. Jurassic deposits accumulated in that trough (Fig. 2). The sinking of the basement was uneven, resulting either from regional cross faults or to differential downwarping. The maximum sinking occurred in the Cis-Dobrudjan part of the downwarp, where the Jurassic is as much as 2,500 m thick; and in the western Cis-Carpathian part where the Upper Jurassic alone is no less than 1,000 m thick. The Jurassic foredeep is locally as much as 100 km wide. Jurassic deposits in the downwarp in Moldavia are arenaceous and argillaceous in their lower part; and carbonate and lagoonal continental, in the upper.

The foredeep was initiated at the close of the Triassic and reached its maximum depth in the Liassic and Middle Jurassic. It may be supposed, in analogy with the Dobrudja, that in the Cis-Carpathian segment of the foredeep, too, the thick limestones, gypsums, dolomites, and red beds rest upon the Liassic arenaceous-argillaceous formation. It is not impossible that this is the formation associated with the original oil accumulations above which were formed the major Miocene gas traps of the Cis-Carpathian gas fields.

The Jurassic subsidence in the foredeep also affected the Lvov trough which was reactivated after a Permian to Triassic interval. In this new subsidence, faults and minor asymmetrical brachyfolds were formed along its margins. An example is the Pelchinskaya fold, about 2 km long by about 1 km wide, of a meridional trend, with the margins dipping as much as 60°. Here, Upper Cretaceous rocks rest transgressively, and with sharp angular unconformity, on the Devonian. It is quite possible that the structure, uncovered in the Rava-Russkaya borehole, is of this type. These structures were formed at the close of the Triassic to the Lower Jurassic along with formation of the Lvov trough.

Toward the very end of the Jurassic, the entire southwestern part of the Russian platform, including the segment of the Jurassic downwarp which had been overlain by deposits, went through considerable uplift, to become dry land in the Lower Cretaceous. In the Upper Cretaceous, the Lvov trough underwent another subsidence which affected an area larger than did the Jurassic but did not spread over the foredeep. For this reason, the Upper Cretaceous isopachs in the Lvov trough have an orientation opening to the north which is different from that of the Upper Jurassic (Fig. 2).

The intensity of the Upper Cretaceous downwarping in the Lvov trough increased sharply. As a result, its outline became asymmetrical, with a very flat northeastern limb: the axis shifted somewhat to the east, with reference to its Jurassic position, and the thickness of the deposits reached 400 m.

The last downwarping of the Lvov trough occurred in the Cretaceous. It has left major traces. Accordingly, this trough, as well as some other formations of the southern Russian platform, may be designated as Upper Cretaceous.

The tectonics of the geosynclinal province proper, subsequent to the Hercynian folding, is quite peculiar. The entire Permian-Triassic-Jurassic section of the main anticlinorium and the adjacent areas is very thin, of the order of several hundred meters. It is marked by many stratigraphic breaks, with entire stages and even divisions missing, such as the Permian, Rhaetian, Hettangian, upper Bajocian, etc. Marine facies of all these systems are characterized by shallow carbonate deposits: dolomites and limestones, in the Lower and Upper Triassic; limestones and marls in the Jurassic. Intrusive bodies of this age are lacking; the extrusive activity was low.

Thus, the vast Permian to Cretaceous interval in the Carpathians, may be regarded

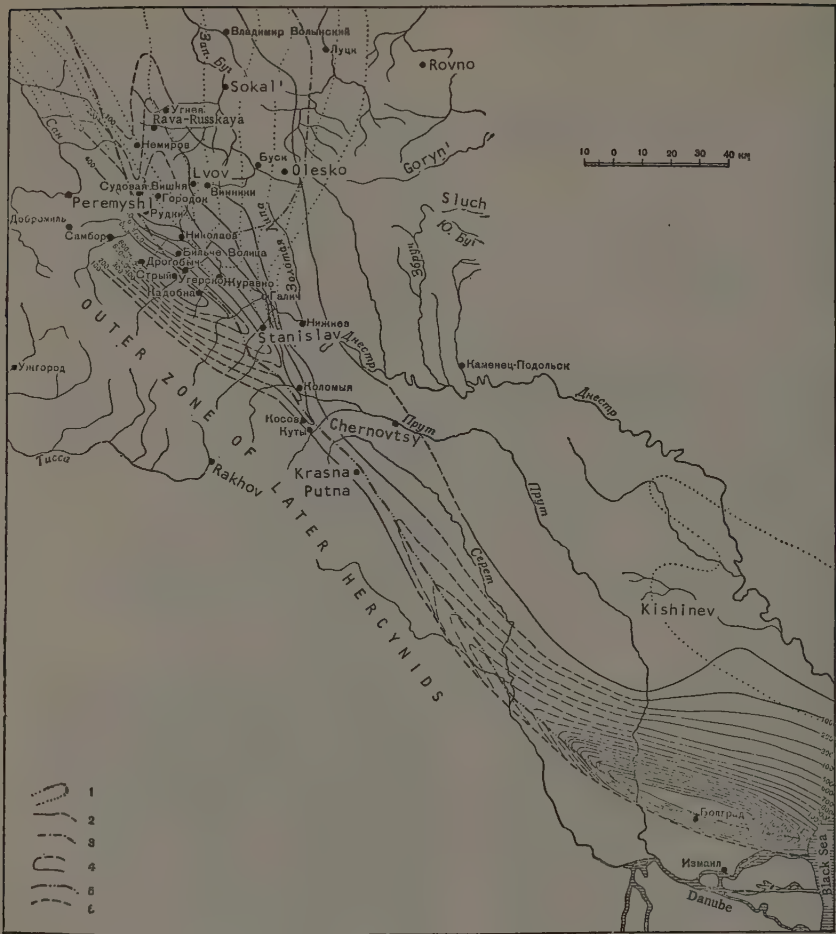


FIGURE 2. Distribution map of upper Paleozoic and Mesozoic downwarps in the southwestern part of the Russian platform.

1 -- Cretaceous downwarps; 2 -- isopachs of the Jurassic; 3 -- conditional boundary of the Lvov Carboniferous syneclise; 4 -- Jurassic downwarps; 5 -- boundary of the Russian platform; 6 -- fault lines.

as a peculiar intergeosynclinal period of dampened tectonic movements. However, the narrow linear facies zones of the Jurassic, along with the uplifts which resulted from the folding in the outer zone, at the beginning and the end of the Upper Triassic, etc. militate against regarding this as a platform period.

At the beginning of the Lower Cretaceous (Upper Valanginian), the central Carpathian structural zone (Fig. 1), between the main and the outer anticlinoria, underwent intensive subsidences. The sharp differentiation of the movement within the zone, and its separation from the adjacent tectonic zones, in the character of its oscillations, contributed to the accumulation of a thick terrigenous carbonate Neocomian flysch. At the end of the Neocomian and in the Aptian, the southern edges of the flysch zone and of the main anticlinorium were uplifted and folded. The differentiation of the relief, brought about by the folding, contributed to the accumulation of thick (as much as 500 meters) conglomerates.

The Cretaceous folding, although very substantial, was localized in a comparatively narrow zone of the main anticlinorium, with a bowlike mountain chain formed there, as a result.

The contemporaneous folds are sharp and overturned. On the whole, the structure of the main anticlinorium is fanshaped. The outer Carpathians have not been affected by this folding.

The early Neocomian differentiation of the inner and outer Carpathian province determined the formation of the margin faults and a revival of volcanism in the southeastern part of the Soviet Transcarpathia, in the main anticlinorium zone, and in Slovakia. Numerous ultrabasic and basic intrusions occurred during the post-Neocomian Lower Cretaceous folding.

Thus, Mesozoic folded structures were formed along the Pannonian massif boundary, on the inside of the future Alpine folded belt. These structures are contemporaneous with the Pacific Mesozoic structures, although differing from the latter in the entire history of their development. The Cretaceous movements in the Carpathians were the harbingers of the Alpine type of folding.

The resulting structure behaved as a major anticline in the course of Alpine history. It was subject to subsidence and erosions and was a source of clastic material. This is why we call it the main Carpathian anticlinorium (Fig. 3) (inner anticlinorium, after A. A. Bogdanov and M. V. Muratov).

The Cretaceous folding brought no substantial changes in the geotectonic conditions of the outer Carpathians: the intensive downwarping of the Lower Cretaceous continued into the Paleogene, varying in its intensity. The thickness of Cretaceous-Neogene flysch and flyschlike deposits here is several thousand meters.

The Oligocene (subsequent to the deposition of the menilite formation) was subject to local but significant uplifts in the flysch zone. By that time, the outer anticlinorium zone and the interior part of the central Carpathian structural zone emerged as uplifts (Fig. 3). It is quite possible that folding took place there, as noted by A. A. Bogdanov [1] and M. V. Muratov.

At the close of the Oligocene, the flysch zone underwent major folding, especially intensive in the outer anticlinorium, with narrow linear folds, overturned chiefly to the northeast, formed as a result. The post-Paleogene folding was inconspicuous in the inner Carpathians. It apparently initiated the major faulting in the southern limb of the main anticlinorium and in the peripheral parts of the Pannonian massif. Faulting and complementary metamorphism have also been observed in the main anticlinorium zone. After the post-Paleogene folding, the entire Carpathian province underwent a major uplift, with the formation of a mountain landscape.

Thus, the Upper Cretaceous to Paleogene stage of development of the Carpathians, which had opened with intensive subsidences, terminated with a late Paleogene folding. Like the Lower Cretaceous, this folding was of a local character, and even more peripheral than the preceding one. Along with a general uplift of the Carpathians, isolaged segments began to sink on normal faults. This subsidence first took place along the boundary between the main anticlinorium and the Pannonian massif, and then along the periphery of the folded province, i. e., between the Carpathians and the Russian platform. A zone of interior troughs was formed in the first instance; and a foredeep, in the second.

Lower and middle Miocene subsidences were of such magnitude that the thickness of the deposits reached 8,000 to 10,000 m in the interior troughs and 2,000 to 3,000 m in the foredeep. In the upper Miocene and Pliocene, narrow lower Miocene troughs were considerably widened, and the foredeep shifted toward the periphery. Both the southwestern parts of the Russian platform and the northern parts of the late Hercynian province were involved in the subsidence. In the inner Carpathians, the subsidence included all of the central Carpathian core and the Pannonian massif.

A revival of the oscillatory movements of the Neogene was closely associated with an intensified igneous activity. Numerous volcanoes sprang into action, from the beginning of the Neogene, chiefly along the periphery of the interior trough zone, where they poured out lavas of various composition, from acid (rhyolites) to the basic (basalts). The volcanism was éspecially intensive at the close of the Miocene to the beginning of Pliocene, i. e., at the time of a general subsidence of the Pannonian central massif.

The maximum volcanic activity coincides with the outpouring of basalts and andesites which make up the Vygorlat-Gutin range; the basic lava was followed by rhyolites and dacites, with all extrusives accompanied by an accumulation of thick tuffs and tuff breccias. Miocene and Pliocene intrusives, however poorly exposed, have been observed in numerous small outcrops.

Such is the tectonic history of the Carpathians

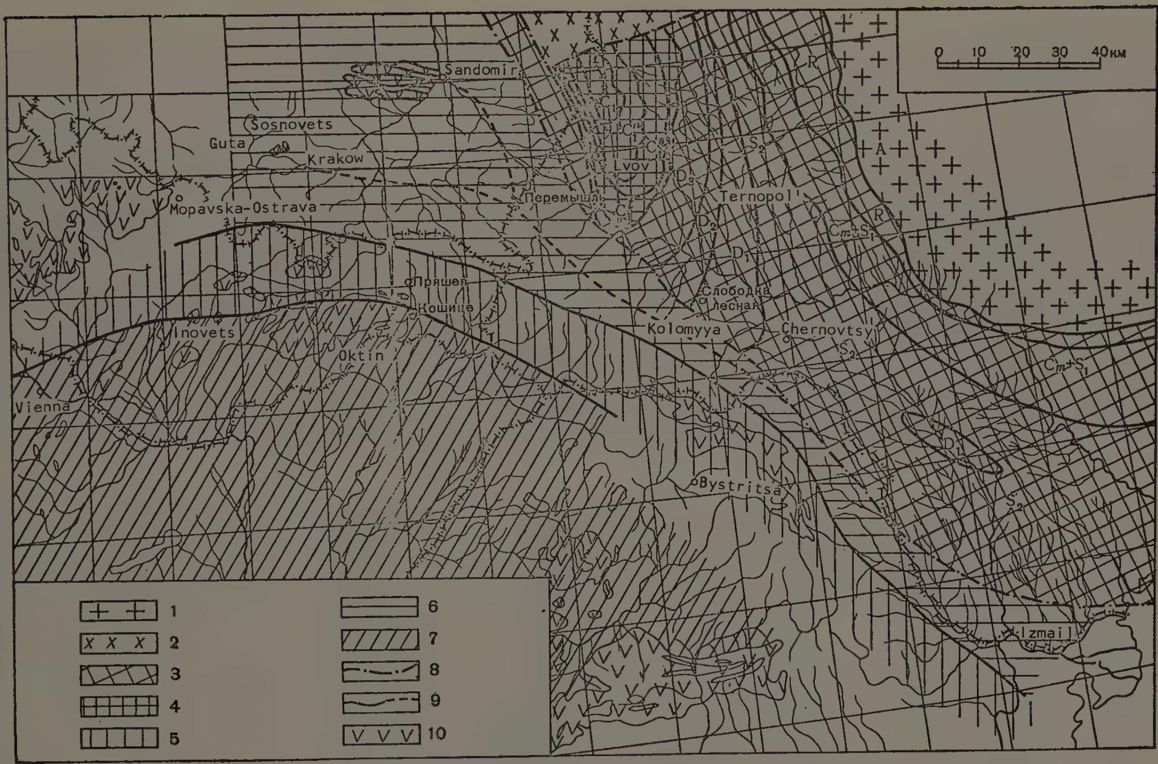


FIGURE 3. Tectonic map of the Paleozoic of the southwestern part of the Russian platform and the Carpathians.

1 -- Ukrainian shield; 2 -- Belorussian massif; 3 -- slope of the massif; 4 -- Lvov trough; 5 -- zone of the main Hercynian anticlinorium; 6 -- Pannonian central massif; 7 -- interior Hercynian zones; 8 -- major faults; 9 -- axis of the margin anticlinorium; 10 -- Precambrian and Paleozoic outcrops in the Carpathians.

and the southwestern Russian platform. The knowledge of this history is very important for a correct understanding of the structure of this heterogeneous province and for a correct tectonic differentiation of the western provinces of the Ukrainian S. S. R. It is clear from this brief historical review that segments in the area have gone through various stages of geotectonic development. This accounts for the difference in individual structures and in the time of their formation.

The following tectonic provinces and zones are suggested for a modern tectonic map of the western provinces of the Ukraine (Fig. 1):

I. Pre-Rhiphean Platforms

1. The Russian platform, with the Ukrainian shield and Belorussian platform, separated by the difference in their position and in the basement structure.

In the structure of the sedimentary mantle and the history of the post-Rhiphean development, the Russian platform is divided into: a) Paleozoic slopes of the shield, complicated by faults and folds; b) the Lvov Cretaceous trough, a Mesozoic platform-type structure, with a Jurassic to Cretaceous thickness of as much as 1,000 to 1,200 m, inherited from a Paleozoic margin syneclise. The trough was initiated in the Jurassic; its development was particularly intensive and came to an end in the Upper Cretaceous.

II. Folded Provinces

1. The Caledonian, Hercynian, and post-Hercynian folded provinces, present in the western Ukrainian S. S. R., are not shown on the map, because they make up the lower structural levels and are not expressed at the surface. (The position of these zones is shown in Figures 2 and 3).

2. The Alpine folded province, with the following tectonic zones:

1) The main anticlinorium, i. e., the central zone of the Carpathian folding, initiated in the Liassic and was completed in the Cretaceous.

2) The central Carpathian megasynclinorium consisting of three subzones: a) The Poloninskiy synclinorium; b) Gorgan-Pertosh anticlinorium; and c) the central synclinorium. This zone, as a whole, underwent considerable Cretaceous and Paleogene subsidences and a terminal Paleogene folding.

3) The outer anticlinorium (end of Paleogene to beginning of Neogene), marked by a system of tectonic scales produced by an overthrust (nappe), as much as 10 km wide, over a fairly flat zone of the Cis-Carpathian foredeep.

4) The Trans-Carpathian interior trough, Miocene in age, with Neogene sediments, 8 to 10 km thick, folded into gentle folds and faulted.

5) The Cis-Carpathian foredeep divisible into three zones, on the basis of the time and the history of their formation: the outer, a platform limb; the central; and the interior, a geosynclinal limb.

Each of these provinces and zones differ from its neighbor in the time of origin, in tectonic history, and in the general types of its structures.

Migration of the folded movements within a geosynclinal province occurred at each orogenic stage, proceeding from the interior of the geosyncline to the platform. Thus, during the Paleozoic mountain-making stage, the Caledonian folding province was located in the inner Carpathians; the Hercynian (Carboniferous phases) included the zone bordering on the outer Carpathians; finally, the post-Hercynian movements were best expressed in the outer Carpathians, at the boundary with the Russian platform.

The Alpine folding represented a new cycle. The ancient Alpine (Cretaceous) folding was most intensive in the main anticlinorium zone; the Oligocene, in the central Carpathian structural zone; post-Oligocene in the outer anticlinorium. The outer and the inner zones of the Cis-Carpathian foredeep, in that order, were formed in the Miocene.

Such was the fairly well-defined migration of folding from the interior of the geosyncline to the platform. The formation and completion of individual tectonic zones proceeded accordingly.

REFERENCES

1. Bogdanov, A. A., OSNOVNYYE CHERTY TEKTONIKI VOSTOCHNYKH KARPAT [MAIN TECTONIC FEATURES OF EASTERN CARPATHIANS]: Sov. Geol., Sb. 40, 1948.

2. Bogdanov, A. A., B. L. Gurevich, and S. Ya., ANOMALII SILY TYAZHESTI I IKH SVYAZ' S GLAVNYMI TEKTONICHESKIMI ELEMENTAMI ZAPADNYKH OBLASTEY USSR [GRAVITY ANOMALIES AND THEIR RELATION TO THE MAIN TECTONIC ELEMENTS OF THE WEST-

ERN PROVINCES OF THE UKR. S. S. R.]: Akademiya NaukSSSR, Izv., ser. geogr. i geofiz., t. 14, no. 3, 1950.

3. Bondarchuk, V. G., TEKTONICHESKIY PODIL RADYAN'SKIKH SKHIDNIKH KARPAT [TECTONIC DIFFERENTIATION OF THE RADYANSK EASTERN CARPATHIANS]: Geol. Zhurn. Akademiya Nauk UkrSSR, t. 14, 1954.

4. Vyalov, O. S., ODSHCHEYE STRUCTURNOYE PODRAZDELENIYE ZAPADNYKH OBLASTEY USSR [GENERAL STRUCTURAL DIFFERENTIATION OF THE WESTERN PROVINCES OF THE UKR. S. S. R.]: Akademiya Nauk USSR, Izv., ser. geol., no. 5, 1953.

4-a. __________, K GEOLOGII FUNDAMENTA PREDKARPATSKOGO PEREDOVOGO PROGIBA [CONTRIBUTION TO THE GEOLOGY OF THE CIS-CARPATHIAN FOREDEEP BASEMENT]: L'vovsk gos. univ., uch. zap., ser. geol., 1955.

5. Dikehshtein, G. Kh., OSNOVYYE CHERTY STRUKTURY ZAPADNOY CHASTI RUSSKOY PLATFORMY V NIZHNEM PALEOZOYE [MAIN STRUCTURAL FEATURES OF THE WESTERN PART OF THE RUSSIAN PLATFORM, IN THE LOWER PALEOZOIC]: Mosk. Ob. Isp. Prir., Bull., nov. ser., t. 28, vyp. 4, 1953.

6. Laskarev, V. D., OBSHCHAYA GEOLOGICHESKAYA KARTA YEVROPEYSKOY ROSII [GENERAL GEOLOGIC MAP OF EUROPEAN RUSSIA]: list 17, Geol. Kom., Trudy, nov. ser., no. 77, 1944.

7. Muratov, M. V., TEKTONIKA I OSNOVNYYE ETAPY RAZVITIYA VOSTOCHNYKH KARPAT [TECTONICS AND PRINCIPAL STAGES OF THE DEVELOPMENT OF THE EASTERN CARPATHIANS]: Mosk. Ob. Isp. Prir., Bull., otd. Geol., t. 22, no. 2, 1947.

8. Naydin, D. P., OSNOVNYYE CHERTY TEKTONIKI L'VOVSKO-LYUBLINSKOY MUL'DY [MAIN TECTONIC FEATURES OF THE LVLV-LUBLIN TROUGH]: Ibid, nov. ser., t. 28, vyp. 3, 1953.

9. Slavin, V. I., TEKTONICHESKOYE RASCHLENENIE KARPATSKOGO OROGENEA [TECTONIC DIFFERENTIATION OF THE CARPATHIAN OROGENY]: Materialy po geol. i gidrogeol. Ukr. geol. upr., za 1946, no. 4, Kiev, 1947.

10. Sobolev, D. N., O GEOLOGICHESKY STRUKTURE ZAPADNOY UKRAINY [THE GEOLOGIC STRUCTURE OF WESTERN UKRAINE]: Sov. Geologiya, no. 12, 1939.

11. Shul'ga, P. L., O PALEOZOYE ZAPADNOY VOLYNI I YUGO-ZAPADNOY CHASTI BRESTKOY OBL. [THE PALEOZOIC OF VOLYNIA AND THE SOUTHWESTERN PART OF THE BRESTSKAYA OBLAST, BELORUSSIAN S. S. R.]: Akademiya Nauk USSR, Dokl., t. 80, nov. ser., no. 1, 1951.

12. Shatskiy, N. S., OSNOVNYYE CHERTY STROYENIYA I RAZVITYA VOSTOCHNO-YEVROPEYSKOY PLATFORMY [MAIN STRUCTURAL AND DEVELOPMENT FEATURES OF THE EAST-EUROPEAN PLATFORM]: Akademiya Nauk SSSR, Izv., no. 1, 1946.

13. Nowak, I., JEDNOSTKI TEKTOŇISZNE POLSKICH KARPAT WSCHODNICH: Lwow, 1914.

14. Szalai, T., AZ ESZAKKELETI KARPATOK GEOLOGIAJA: Magyar állami földt. int. évk, v. 38. Budapest, 1947.

15. Teisseyre, W., METODA KRYPTOKETTONIKI PODLOZE KARPAT: Kosmos, Lwow, 1926.

16. Tětianeff, M., LES GRANDES LIGNES DE LA GEOLOGIE ET DE LA TECTONIQUE DES TERRAINS PRIMAIRES DE LA RUSSEI d'EUROPE: Ann. de la sol. Géol. de Belgique, 1912.

17. Uhlig, V., UBER DIE TEKTONIK DER KERPATHEN: Sitzungsber. Osterr. Akad. Wiss. Math. -naturwiss. Kl. Abt. 1. Bd. 116. Wien, 1907.

18. Zych, W., OLD-RED PODOLSKI: Pracé Inst. geol. Warszawa, v. 2, pt. 1, 1927.

The M. V. Lomonosov
Moscow State University

Received September 14, 1957.

UPPER CRETACEOUS VOLCANIC FORMATIONS OF THE UPPER AMUR REGION[1]

by

M. S. Nagibina

A description of the composition and position of the upper Amur area volcanics is given, for the first time. Emphasis is put on the clean-cut spatial relationship of extrusives with major faults along the boundaries of major structural elements, and their close association with large dike bodies which represent the roots of these extrusives.

* * * * *

Fairly widely developed in the upper Amur region are volcanic formations (Fig. 1) of various composition, resting unconformably upon eroded Precambrian and Paleozoic surfaces, on Jurassic and Lower Cretaceous deposits including vein extrusives which cut them.

The volcanics from areas of the upper Amur region have been mentioned many times by field geologists; up to now, however, they have been but pporly known. There is no reference to this interesting formation in the literature on the upper Amur region.

DISTRIBUTION AND OCCURRENCE OF VOLCANIC FORMATIONS

The upper Amur volcanics form a series of fairly complex sheets, usually rather undisturbed, formed in sedimentary troughs with limbs dipping at angles from 15° to 80° (Fig. 2). These troughs are usually asymmetrical, and are located along the periphery of large uplifts, fringed by faults and made up of Paleozoic or older metamorphic formations; or they are on the periphery of downwarps filled with thick Jurassic and Lower Cretaceous deposits.

A number of smaller volcanic outcrops is associated with large faults marking comparatively small horsts of ancient rocks or which cut upper Mesozoic sediments.

Large areas of extrusive formations are located along the boundary between the Gonzhinsk prong and the Amur and Amur-Zeya Mesozoic downwarps, and also in the peripheral parts of that prong. Here belong the volcanic rocks of the Taldan Station area (the Taldansk trough); those of the middle course of the Burinda (left tributary of the Amur); of the middle basin of the Ulunga River (right tributary of the Zeya); and of the lower course of the Urkan River and its left tributary, the Arbi River.

Volcanic formations are also developed along the major, south Tukuringra-Dzhagdinsk anticlinorium and younger Mesozoic and Cenozoic troughs, in the vicinity of the Zeya and in the upper courses of the Arbi and Tynda Rivers (Ukranskaya), as well as in the east of the upper Urkan trough. In addition, small areas of extrusive rocks are present within the Mesozoic downwarps; in the vicinity of the village of Ignashino (Ignashinsk trough); at the village of Chernyayevo, on the northwest edge of the Zeya-Bureya depression; and in the middle course of the Dep River (near Utesnoye).

Large areas of volcanic formations are present in the Zeya-Selemdzhinsk watershed, along the boundary between the Bureya central massif and the Tukuringra-Dzhagdinsk anticlinorium, in the upper course of the Selemdzha, where extrusive and sedimentary formations are disposed in a belt, as much as 30 km wide and more than 150 km long, and trending northwest nearly latitudinally. To the west, along the projection of this belt south of the Tukuringra-Dzhagdinsk anticlinorium, volcanics are present in the upper Mamyn basin, also in a band trending slightly north

---

[1]Verkhemelovyye vulkanogennyye obrazovaniya verkhnego Priamur'ya.

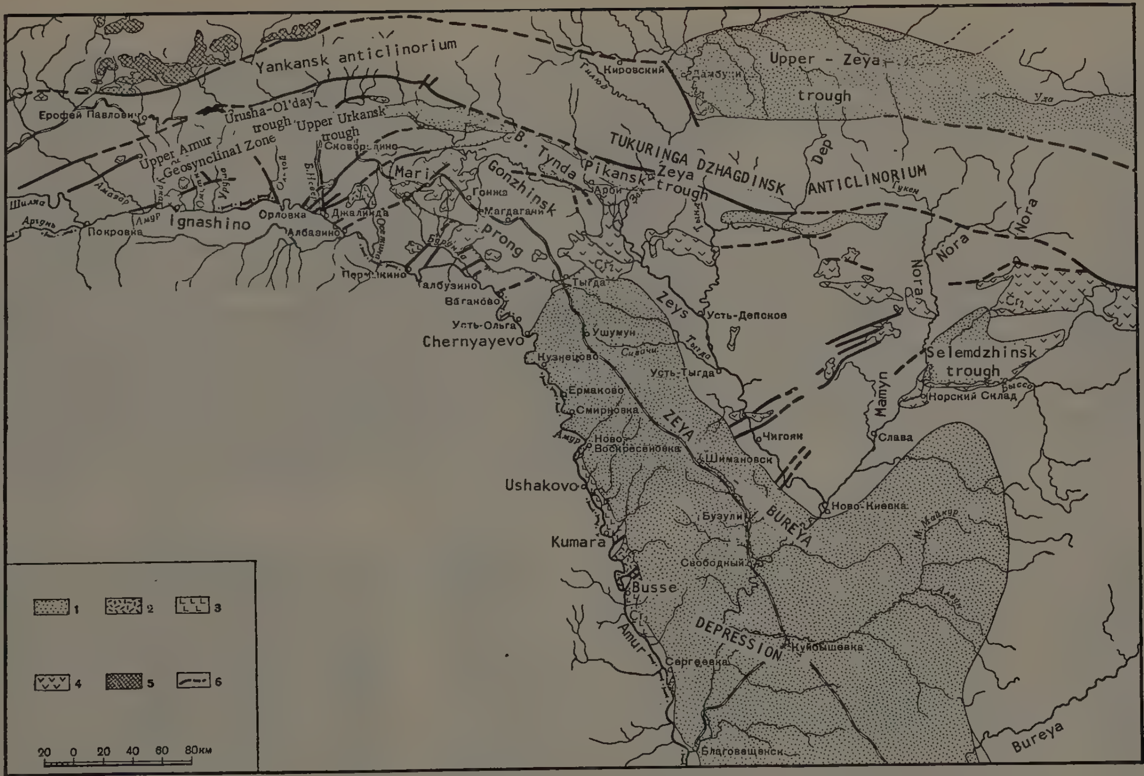


FIGURE 1. Distribution of Upper Cretaceous volcanics in the upper Amur region.

1 -- depressions with unconsolidated deposits of the Tsagayan series; 2 -- acid extrusives and pyroclastics (Cr_2); 3 -- basic extrusives and pyroclastics (Cr_2); 4 -- undifferentiated extrusives and pyroclastics (Cr_2); 5 -- undifferentiated upper Mesozoic formations; 6 -- faults.

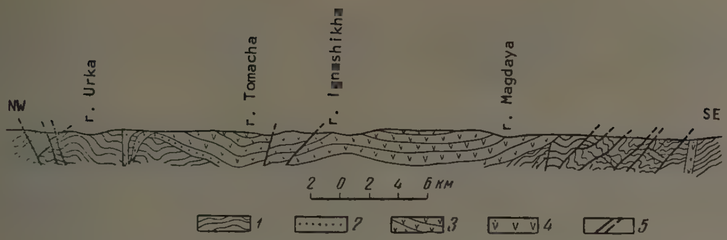


FIGURE 2. Cross section of Upper Cretaceous extrusives on the bank of the Amur, near Ignashino (Ignashino sedimentary depression).

1 -- Devonian deposits; 2 -- tuff conglomerates and sandstones; 3 -- basalts, andesites, and their tuffs (Cr_2); 4 -- dikes of various compositions; 5 -- normal and reverse faults.

The composition of the upper Amur extrusives is very diversified, with extrusives and pyroclastics of intermediate composition predominating, and with acid and basic extrusives and pyroclastics much less common. The intermediate rocks are represented by porphyrites: biotitic, biotite-hornblendic, pyroxene; also by tuffs and volcanic breccia of corresponding composition.

The occurrence and structure of the extrusives are not always observable because of poor outcrops. Only locally are there good exposures, such as occur along the Amur bank near Ignashino, and in the area of Kumara and Busse; in the Urkan valley; in cuts along the Amur Railroad, near Taldan Station, and at other points. They reveal the fairly complex structure of the extrusive formations consisting of individual flows of various composition. In most instances, it is impossible to establish their exact sequence. However, a study of sections from various areas reveals that basic lavas and pyroclastics, chiefly, lie at the base of many volcanic outcrops of this age.

It appears that the basal-extrusive beds are associated with sandstones, observed among the extrusives along the railroad stretch from Taldan to Voskresenovka; also with the tuffaceous sandstones and tuffs exposed in the Amur Railroad cut, between the Taldan Station and the Mari Siding. Locally the base of the section is represented by small-pebble conglomerates alternating with basic extrusive sheets.

According to V. Z. Skorokhod,[2] sheets of acid extrusives lie above the basic lavas and their tuffs, along the Never River, north of Skovorodino (Rukhlov). The same relationship has been observed in the Kumara and Busse area (according to S. A. Muzylev, 1942), and on the left bank of the Amur, below Gornoye Kalashnikovo.

The maximum thickness of the upper Amur volcanics is locally as much as 1,500 m. The areas of extrusive rocks are commonly associated with veins and dikes corresponding in their composition to the sheets of porphyrites, andesites, and dolerites, and also of acid rocks (quartz porphyrites and felsites), which apparently represent the roots of these sheets. The relationship between the extrusives and their roots is especially clear along the major south Tukuringra fault which fringes the Tukuringra-Dzhagdinsk anticlinorium in the south. In the vicinity of the Zeya, this fault zone displays intrusive contacts of purple-gray and dark-red porphyrites with diorites which cut Proterozoic metamorphic schists. To the south, along the edge of the Pikansk trough, the same purple-gray and gray porphyrites form sheets plunging beneath the unconsolidated Tertiary of the trough. The drilling by the Zeya expedition of the Leningrad Hydroelectric Project revealed the presence, under these deposits, of the same porphyrite sheets interbedded with agglomeratic and porphyritic tuffs.

Northwest, along the south Tukuringra fault, N. A. Bogdanov reports the presence in the Arbi River exposures (left tributary of the Urkan) of strongly cataclastic and schistose biotite-hornblende Paleozoic granites, cut by gray diorite porphyrites changing to the south to gray hornblende porphyrites. These in turn change to agglomeratic tuffs and volcanic breccias of coarse diorite porphyrite fragments, attaining 15 to 30 cm. The porphyrite sheets strike north of west, almost latitudinally, parallel to the south Tukuringra fault zone, and dip southwest, at 45° to 50°.

[2] Skorokhod, V. Z., Main features of the geologic structure of the Soviet Far East, Vladivostok, 1941.

To the south, the biotite-hornblende porphyrites are interbedded with tuffs and agglomeratic porphyrite tuffs. The thickness of porphyrites and their tuffs here is about 800 to 1,000 m.

To the northwest, along the same south Tukuringra fault, in the Bol'shaya Tynda (Urkanskaya) Valley, lower Paleozoic diorites are cut by a series of small parallel faults accompanied by zones of crushing and milonitization, with a local penetration by diorite porphyrite dikes. Half a kilometer to the south, below the confluence of the Malaya and Bol'shaya Tynda, strongly cataclastic diorites are overlain by hornblende porphyrites, in sheets similar to those interbedded with tuffs in the Arbi Valley. Here, they are 100 to 150 m thick.

Excellent exposures of volcanic basalt breccias, similar to the crater facies, are present on the left bank of the Amur, near the fault contact with ancient crystallines of the Novo-Innokent'yevsk prong. Farther downstream, these breccias change to basalt and andesite-basalt sheets. Away from the contacts with ancient rocks, the latter are practically horizontal, separated by uneven surfaces of lava flows, which suggest numerous paroxysms of volcanic activity. The source of these flows appears to have been the fault zone terminating the Novo-Innokent'yevsk uplift.

THE COMPOSITION OF VOLCANIC FORMATIONS

a) Basic and Intermediate Varieties of Extrusive and Pyroclastic Rocks

Basalts, andesite-basalts, and andesites. Basalts have a very small distribution in the upper Amur region, with only the lower part of the extrusive-sedimentary section exposed. Together with andesites and their tuffs, the basalts occur in flows on the left bank of the Amur, near the villages of Ignashino, Kumara, and Ushakovo; on the Osezhina-Ul'dugichi (right tributaries of the Amur); on the right bank of the Topak River; and on the Amur-Pravaya Burinda watershed. In addition, basalts form dikes which cut Jurassic arenaceous and argillaceous deposits along the left bank of the Amur, near the mouth of the Malaya Burgal'; and cut Triassic and Lower Jurassic rocks near the Topak area of basalt and andesite flows.

Basalts of the Ignashino area, on the left bank of the Amur, are of a different texture and structure. Black to dark gray aphanitic basalts alternate with amygdaloid basalts. They consist of basic platioclase, olivine, augite, ore minerals, and secondary minerals such as iddingsite, chlorite, and calcite.

Aphanitic varieties occur among basalts, with a porphyritic, intersertal and amygdaloid texture. There are phenocrysts of euhedral labradorite, locally zonal, as much as 1.5 mm long, and to a smaller extent of euhedral grains of olivine and augite. The groundmass of basalts exhibits an intersertal or hyalopilitic texture. The amygdaloid basalts contain numerous amygdules, very few larger than 1 or 2 mm in diameter, extremely diversified in form and filled with chlorite alone or with chlorite and chalcedony. The secondary alterations of basalts are inconspicuous, being expressed chiefly in the replacement of dark-colored minerals by iddingsite, chlorite, and calcite. The olivine grains have been fully replaced in most instances by iddingsite, less commonly by iddingsite and calcite. The labradorite grains are usually transparent and very few contain inclusions of sericite scales. The amygdaloid basalts are locally interbedded with agglomeratic basalt and andesite-basalt tuffs with flows of gray andesite-basalts.

Higher in the extrusive section, near Ignashino, there is an alternation of gray, greenish gray, and brick-red andesite and andesite-basalt flows.

The structure of individual andesite flows can be seen in the Amur River bank exposures. The lower part of the flow usually is made up of dark gray, dense, aphanitic andesites, whereas the upper part is reddish gray and vuggy. Several such flows can be counted here, locally interbedded with agglomeratic tuffs and volcanic andesite breccias.

The andesites differ from the basalts chiefly in their mineral composition. They lack olivine grains and carry only an insignificant amount of augite. The andesite texture is also diversified: intersertal, hyalopilitic to vitreous, with amygdaloid and flow textures not uncommon.

Basalts which outcrop in the lower part of the section, along the right bank of the Topak, a left tributary of the Osezhina River, and in the valley of the Bol'shaya Gal'ka, the left tributary of the Burinda River, present gray to purple-gray amygdaloid flows, separated by uneven, bumpy surfaces. Mineralogically, they are not different from the Amur basalts, but they display a differential crystallization and a microdiabase and porphyritic texture with a hyalopilitic groundmass.

Basalt flows of the same composition are located on the left bank of the Amur, south

of the Novo-Innokent'yevsk ancient rock prong, near the villages of Novo-Voskresenovka and Kumara.

Here, the Amur banks present a series of typical vertical cliffs, tens of kilometers long, made up of interbedded basalts, andesite basalts, and andesites, with black, purple-gray to gray varieties of a dense aphanitic and trachytic to amygdaloid texture. Near the village of Kumara (Kumarskiy Cliff) the basalt lavas are cellular, with individual almost man-size cavities.

South of the basalt and andesite flow area, at the margin of the Blagoveshchensk prong, gneisses and granite-gneisses are cut by dikes of black augite dolerites and andesite-basalts, as much as 15 m thick, striking N. 80° E., and dipping southeast at 75°. These dikes appear to be the roots of the above-described basalt and andesite-basalt flows.

According to N. A. Sushkov, A. Z. Lazarev, and others, basalt and andesite-basalt flows are common in the Zeya-Selemdzhinsk region; in the upper reaches of the left tributaries of the Nora, Burinda and Meun Rivers; along the lower course of the Nora; and in the Dayenikha Basin and elsewhere.

Basalts which form the dikes cutting the Mesozoic arenaceous and argillaceous deposits in various upper Amur localities are of the same composition as the above-named basalt flows. Similar in composition are porphyritic olivine dolerites forming dikes and larger stocklike bodies in the basin of the Osezhina River and its left tributary, the Neven, east of Topak Valley and west of the Bol'shaya Gal'ka Valley. On the Neven-Osezhina watershed, porphyritic olivine dolerites, gabbro-diabases and gabbro porphyrites cut the Osezhinsk formation (J_3-Cr_1) and upper Mesozoic porphyritic biotite-hornblende granites of the Uskalinsk massif.

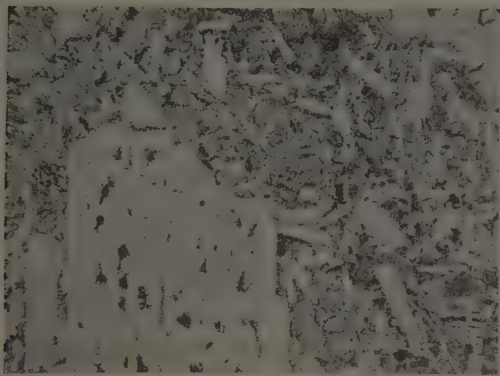


FIGURE 3. Olivine dolerite; Osezhina-Neven watershed.

Photomicrograph; slide 220; x 46.

The porphyritic olivine dolerites are black dense rocks with a well-defined porphyritic structure. Macroscopically, they exhibit euhedral labradorite phenocrysts, as much as 0.5 cm long. Their mineral composition is basic plagioclase (labradorite), olivine, and augite, with accessory ore minerals and secondary iddingsite and serpentine. The plagioclase predominates, with a considerable amount of dark-colored minerals, olivine, and augite. The phenocrysts are formed by coarse (as much as 5 mm long) euhedral crystals of labradorite (Fig. 3), locally resorbed by the groundmass, and by augite and olivine. The plagioclase phenocrysts usually predominate, with finer dark mineral incrustations also numerous. The finely crystalline groundmass only fills the space between the coarse crystals of plagioclase, olivine, and augite. The groundmass of olivine dolerites, developed on the Neven-Osezhina watershed, consists of fine crystals and platelets of plagioclase and fine grains of augite and olivine in a brown-black, almost nonpolarizing, vitreous matrix. The olivine grains have been fully replaced (with rare exceptions) by green iddingsite. Plagioclase and augite have been almost unaffected by secondary alterations.

Typical for the composition of olivine

dolerite from the Neven-Osezhina watershed is the analysis by the Chemical Laboratory of the Geologic Institute, Academy of Sciences, U. S. S. R. (Ye. N. Shishova, analyst) (see table below).

In their composition, the olivine dolerites are similar to diabase porphyrites (the Uryumank basin) which cut the Turginsk formation (Cr_1), differing from them only in the somewhat lowered value of coefficients a and b. Moreover, the Neven-Osezhina watershed olivine dolerites are similar in their composition to basalt lavas of the northern group of the Kamchatka volcanoes (Tolbachik Volcano): S = 61.8; a = 9.6; b = 19.5; c = 9.1. The Neven-Osezhina watershed olivine dolerites are cut by veins of quartz porphyries.

These vein and hypabyssal basic rocks, located near the area of olivine basalts in the Topak Valley and in the upper course of the Neven, appear to be the roots of these basalt flows exposed by erosion. The quartz porphyry dikes, cutting the olivine dolerites, possibly are also genetically related to the acid extrusive flows of this region.

Augite porphyrites are transitionally related to the above-described basalts. They are dark gray, gray and brown-purple dense rocks in the lower layers of the extrusive sequence developed in the Topak Valley; on the right bank of the Chalaya River (right tributary of the Urkan); along the Amur Railroad, between Taldan Station and the Mari Siding, and west of Taldan. Their mineral composition is plagioclase, augite, biotite, hornblende and very rare quartz; accessory minerals, apatite, ore minerals; and secondary chlorite, sericite, calcite, quartz and iron hydroxides. Plagioclase predominates although there is a considerable amount of augite. Biotite and hornblende are present only in varieties transitional to biotite-hornblende porphyrites. Phenocrysts are represented by euhedral crystals of basic plagioclase and augite and by considerably less common fine grains of hornblende and biotite. Only in one locality, between Taldan Station and the Mari Siding, the augite porphyrites contain strongly corroded rare phenocrysts of quartz. In the Chalaya River, augite porphyrites, the phenocrysts of dark minerals, biotite, and hornblende are fringed by dark opacite.

Oxides	Quantity %	Molecular Quantity	Numerical characteristic, after A. N. Zavaritsky	
SiO_2	52,86	821		
TiO_2	1,30	16	$S=65,5$	$C'=7,43$
Al_2O_3	18,20	178	$a=10,0$	$m'=50,56$
Fe_2O_3	4,28	27	$b=16,4$	$f'=41,49$
FeO	2,88	40	$c=8,1$	$n=70,58$
MnO	0,10	1		
CaO	7,10	127		
MgO	4,58	115		
Na_2O	3,02	48		
K_2O	1,92	20		
P_2O_5	0,04	—		
H_2O^+	1,80	—		
H_2O^-	2,34	—		
CO_2	0,01	—		
	100,43			

Note: Comma represents decimal point.

Nearly latitudinal dolerite dikes, as much as 500 m thick by 4 to 5 km long, were described in 1950 by A. Z. Lazarev and others, from the basin of the left tributaries of the Nora River. These dikes are located near the area of flow formations in a wide, nearly latitudinal belt; apparently they, too, are the roots of basalt flows interbedded with andesites, their tuffs, and volcanic breccias.

The groundmass of augite porphyrites has an intersertal or hyalopilitic texture and consists of very fine plagioclase platelets and fine augite grains, with the interstitial space filled with an amorphous vitreous mass with a multitude of very fine ore-mineral grains. Secondary alterations of the augite

porphyrites are locally very intensive. The rock has been cut by calcite veins, and the dark minerals have been partially replaced by chlorite and microcrystalline quartz.

Hornblende porphyrites are less common in the extrusive sequence. We have observed these porphyrites in flows, in the Topak Valley, in the vicinity of Taldan Station, and in the valley of the Arbi and Bol'shaya Tynda Rivers. More commonly, they form veins and dikes which cut deposits of various ages near the extrusive areas and those of Upper Cretaceous granitoids of the Uskalinsk massif, as well as others. A number of hornblende porphyrite dikes cut Precambrian gneisses near Gonzha and Unyr' Stations of the Amur Railroad.

Hornblende porphyrites, which form sheets in the Tanaka Valley, are similar to the local augite porphyrites with which they are apparently related. Hornblende porphyrites are gray dense rocks with a distinct porphyritic texture. They consist of plagioclase and hornblende; apatite and ore mineral as accessory minerals; and sericite, chlorite, and calcite, as the secondary. The texture is distinctly porphyritic. Phenocrysts of euhedral plagioclase and hornblende are common. The groundmass has a diabase texture and consists of tabular plagioclase crystals and irregular hornblende grains. The ore mineral occurs in numerous inclusions, both in the goundmass and in the plagioclase and hornblende phenocrysts. They have been intensively altered by secondary processes: carbonitization and chloritization.

The hornblende porphyrites which form veins along the left bank of the Topaka and near Gonzha Station differ from the sheet porphyrites in texture and in the considerably larger hornblende content. The hornblende is common as large green phenocrysts, and is also present to a considerable extent in euhedral grains in the groundmass. The plagioclase phenocrysts are euhedral. The groundmass is microdioritic in texture and contains small amounts of xenomorphic quartz grains. The secondary alterations of vein hornblende porphyrites are fairly intensive, with plagioclase replaced to a considerable degree by epidote, calcite, and sericite; and dark minerals, by chlorite (penninite).

Biotite-hornblende porphyrites are the most common among the extrusive porphyrites. Externally, they are fairly diversified, being green, light green, green-gray, dark gray, pink-gray, violet-gray to yellow-gray, dense rocks with a distinct porphyritic texture and locally with an uneven, bumpy surface. They are developed in the vicinity of Taldan and Promyslovaya Stations; in the right bank area of the Magdagachi Basin; in the Topak Valley, and elsewhere, where they occur in flows alternating with those of biotite and quartz porphyrites. They also form a series of dikes near the extrusive area. These dikes cut deposits of various ages, including upper Mesozoic granodiorite porphyrites. Their mineral composition is plagioclase, hornblende, biotite, quartz, with accessory sphene, apatite, ore minerals (at times sulfides), and secondary sericite, chlorite, epidote, calcite, and quartz. The texture is distinctly porphyritic. The quantitative ratio of the principal rock-forming minerals is very varied, as is the groundmass texture of these porphyrites. Plagioclase predominates, with some varieties carrying as much as 25 percent hornblende. The biotite content is usually low, increasing in varieties transitional to biotite porphyrites. The groundmass commonly carries a small amount of quartz, filling the space between the plagioclase platelets and grains of dark minerals. The groundmass texture is microdiabase or microdiorite, transitional to the intersertal.

Phenocrysts are represented by coarse euhedral plagioclase grains, as much as 6 mm long, locally making up glomerophyric aggregates, and by smaller crystals of hornblende and biotite. The hornblende phenocrysts are euhedral, many carrying inclusions of ore minerals. The extinction angle, $c{:}\gamma = 15°$. The biotite phenocrysts are small, brownish, irregular, less commonly euhedral.

The secondary alterations of these porphyrites (chloritization, epidotization, and carbonatization) are fairly intensive and very uneven. In some flows, the dark minerals are fringed with opacite and locally completely replaced by iron hydroxides.

Biotite-hornblende porphyrites of the right bank area of the Topak and Magdagachi Rivers differ from the above-described Taldan Station porphyrites in both the composition and texture of the groundmass. Their groundmass is poorly crystallized, locally vitreous, with a characteristic intensive opacitization and a nearly complete replacement of dark-mineral phenocrysts by iron hydroxides.

In the eastern limb of the Taldan trough, hypabyssal granitoids (granite porphyrites and granodiorite porphyrites) emerge from beneath the porphyrite flows. They are cut by numerous small dikes, 1 to 2 m thick, of gray to green-gray biotite-hornblende porphyrites. These dikes strike N. 50-60° E., dipping chiefly to the northwest.

Two varieties of these dikes may be distinguished in their composition and texture. One of them is almost identical with the biotite-hornblende flow porphyrites, developed south of Taldan Station. These dikes probably

are the roots of those Taldan flows.

Biotite porphyrites are transitionally associated with the biotite-hornblende. They are not as well distributed as the latter and locally are interbedded with them in flows. These are yellow-gray to violet-gray rocks with a distinct porphyritic structure. They differ from the biotite-hornblende porphyrites only in their lack of hornblende in phenocrysts. The phenocryst biotite is reddish brown. In brown-violet varieties, common south of Taldan Station, the biotite phenocrysts are fringed with opacite of completely replaced by iron hydroxide.

Quartz porphyrites are fairly common in the extrusive complex. They are green to green-gray dense rocks with a well-developed porphyritic texture. Flows of quartz and biotite, as well as of biotite-hornblende porphyrites, alternate in the Taldan area and south of there, also in the area of Mari Station, where they apparently make up the uppermost extrusive layers. In addition, quartz porphyrite dikes cut the older rocks near the extrusive area. Mineralogically, they are similar to the biotite and biotite-hornblende porphyrites, differing from the latter by the presence of quartz in phenocrysts. The quartz phenocrysts are varied in size, are irregular or rounded, commonly strongly corroded by the groundmass. Besides such usual extrusive accessories as sphene, ore minerals, and zircon, many phenocrysts of quartz and plagioclase carry small tourmaline grains.

The groundmass of quartz porphyrites consists of the finest platelets or small tabular crystals of plagioclase and hornblende and small amounts of biotite. Quartz is unevenly distributed in the groundmass, with its grains forming small accumulations among the plagioclase and dark-mineral grains. The degree of crystallization, the texture, and the quantitative ratio of the minerals in quartz porphyrites are very inconsistent.

With few exceptions, quartz porphyrites have usually been intensively altered by secondary processes. The plagioclase grains are commonly sericitized and replaced by epidote and calcite. Dark minerals locally have been nearly completely replaced by chlorite (penninite) and partly by calcite, epidote, and iron hydroxide. Porphyrites of the same composition were described in 1950, by A. Z. Lazarev and others, south of the Tukuringra-Dzhagdaninsk anticlinorium; in the upper Mamyn basin, on the watershed between the Yelna, Polunochnaya, and Adamikha Rivers. Here, the porphyrite flows rest upon Silurian deposits and Paleozoic granitoids, making up the summits of a small mountain group, 500 to 892.7 m above sea level. The porphyrites are represented by hornblende and biotite-hornblende varieties, also by quartz porphyrites. The groundmass of some flows contains numerous spheroidal amygdules filled with radial aggregates of pale-green zeolites. According to the same investigators, a large area of volcanic exposures to the south, and trending northwest for about 100 km, is also made up chiefly of gray to green hornblende and biotite porphyrites, and less commonly, augite porphyrites. These porphyrites alternate with tuffs, agglomeratic tuffs, and volcanic porphyritic breccias.

Volcanics of the same composition were described by V. V. Onikhimovskiy, in 1948, from the Nora-Mamyn watershed, where hornblende-porphyrite flows, as much as 300 m thick, rest upon ancient granites. Onikhimovskiy believes that these porphyrites are transitionally associated with diorite porphyrites which appear to be their roots.

Porphyritic tuffs are found in the lower part of the Taldan trough section. An alternation of porphyritic and agglomeratic tuffs has been observed in the lower course of the Chalaya and along the Amur Railroad, between Taldan Station and the Mari Siding. Externally, they are gray-green to dark gray rocks with a distinct clastic structure. The tuffs consist of irregular fragments of platioclase (commonly zonal), biotite, hornblende, and small porphyrite fragments, as much as 2 mm long. Augite and other porphyrites occur among the fragments, more or less crystallized. They are accompanied by brown volcanic glass and very rare metamorphic sandstones which underlie the extrusive sequence. The fragments are cemented with a greenish brown, weakly polarizing vitreous substance, with numerous green chlorite scales, fine-grained ore minerals, epidote, and locally of microcrystalline quartz. In some localities, the tuffs are schistose and cataclastic.

Agglomeratic tuffs form thin beds and lenses in porphyritic tuffs. Their thickness usually is measured in a few meters. They usually consist of porphyrite and basic extrusive fragments, of various size and form (1 to 5 mm), with small plagioclase and dark-mineral fragments (commonly opacitized), the whole cemented with a weakly polarizing substance carrying numerous chlorite scales, and iron hydroxides.

Tuffs and agglomeratic porphyritic tuffs with a similar composition are also developed elsewhere in the upper Amur region, in alternations with porphyrite flows (the basin of the Nora and Mamyn Rivers and other localities).

Tuffaceous sandstones have a small distribution in the extrusive complex at its base, where they alternate with tuffs and agglomer-

atic tuffs. They are gray-green stratified rocks consisting of fine, angular, less commonly, poorly rounded grains of quartz and plagioclase, commonly sericitized, and of numerous biotite fragments, very fine platelets of plagioclase, and fragments of brown volcanic glass. The fragments are cemented with a green-gray, poorly crystallized argillaceous material, filled with chlorite scales and locally with microcrystalline quartz. Their structure is foliated. Laminae, chiefly of coarser (as much as 0.3 mm) clastic grains of quartz and feldspar, alternate with those of finer pyroclastic material -- finest transparent platelets of plagioclase and angular fragments of dark minerals and brown volcanic glass. The thickness of these laminae is measured in millimeters and centimeters. The tuffaceous sandstones locally have been altered by secondary processes, carbonatized and chloritized, with epidote cement.

Less common among the tuffaceous sandstones are thicker (as much as several meters), gray sandstones, chiefly arkosic, with only isolated fragments of volcanic glass.

b) Acid Extrusive and Pyroclastic Rocks

Acid extrusives and pyroclastics are of secondary importance in the extrusive complex. Their exposures were observed in the upper course of the Burinda River, near the mouth of the Bol'shaya Gal'ka, and in the right bank area of the Magdagacha. N. P. Savrasov mapped, in 1933, a large area of acid extrusives in the basin of the Burinda's left tributaries. In addition, other authors -- A. K. Arsen'yev (1924), A. I. Khlaponin, A. A. Leontovich, and V. D. Prinada (1939) -- noted the presence of acid extrusives in the upper Amur basin. East of there, on the left bank of the Amur and in the Zeya-Selemdzhinsk watershed, acid extrusives were described by S. A. Muzylev (1941), A. Z. Lazarev (1950), and the author (1950, 1951).

In the upper course of the Burinda, these formations are developed in the southern part of the Taldan trough where they lie in flows on biotite-hornblende granitoids, cut by small granodiorite porphyritic stocks. They are represented here by light-gray to light-yellow porphyrites and felsites, more or less crystallized, with green-gray perlites developed in their midst. Alternating with the flows of acid extrusives are quartz porphyry tuffs, of a subordinate character.

Most common among the acid extrusives are quartz porphyrites and felsites, consisting of quartz, K-feldspar, oligoclase, biotite, accessory zircon, and ore minerals, and having a porphyritic texture. The finely-crystalline groundmass of quartz and K-feldspar contains disseminated fine (not more than 1 mm) inclusions of oligoclase and to a smaller extent of quartz and biotite. The oligoclase inclusions are euhedral, commonly, with a zonal structure, with the interior part corresponding to oligoclase-andesite, in its composition. The oligoclase crystals are mostly transparent, at times pelitized. The quartz inclusions display irregular, rounded, corroded, less commonly regular crystallographic bipyramidal forms, with but slightly rounded outlines. The concentration of quartz inclusion is inconsistent, usually not great. Biotite occurs in fairly small, euhedral, greenish-brown inclusions, as much as 0.5 mm long.

The volume of groundmass exceeds that of the inclusions. The groundmass is differentially crystallized, micropegmatitic, and microcrystalline. Its flow structure, emphasized by the bands of differentially crystallized quartz and feldspar is typical of felsites. Numerous cavities filled with chalcedony are present, in places.

Along with poorly crystallized felsites, there are fairly common vitreous rocks: perlites. They, too, contain inclusions of acid plagioclase, quartz, and biotite, in a vitreous mass with a distinct perlitic structure (Fig. 4). Discernible in the perlite mass are quartz microlites and fine spherulites of green chlorite, distributed in the central part of the cracks of the structure. The groundmass of quartz porphyrites on the right bank of the Magdagacha watershed has a cellular (bubbly) structure. Secondary alterations are almost lacking in the acid extrusives.

Quartz porphyritic tuffs are developed along with the acid extrusives apparently alternating with the latter. They are light yellow, violet-gray to light gray rocks, with a distinct clastic texture. They consist of assorted fragments (as much as 2 cm long) of quartz porphyrites, more or less crystallized, and numerous small angular fragments of quartz, K-feldspar, acid plagioclase, and biotite, all cemented with a yellow, weakly polarizing vitreous substance, locally with microcrystalline quartz. The biotite flakes are commonly opacitized. The tuffs are divided into fine grained and agglomeratic on the basis of their component fragments.

Flows of quartz and felsite porphyrites, alternating with tuffs and volcanic breccias, are developed also far to the east, on the left bank of the Amur, near the villages of Simonovy Luzhki and Korsakovo (Korsakov Bends), where they are represented by contrasting rocks: light gray, pink-gray, lilac, reddish-violet, and less commonly greenish. They rest on eroded, ancient, metamorphic

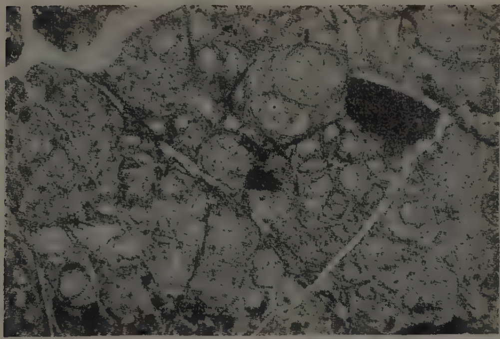


FIGURE 4. Perlite from the Gal'ka River (left tributary of the Burinda)

Photomicrograph, thin section 30; x 46.

schists.

Quartz porphyrites of the Korsakov Bends are light lilac-colored rocks with a porphyritic texture and euhedral crystals of albite and biotite. Their groundmass consists of microcrystalline quartz and K-feldspar. It exhibits an unevenly crystallized flow structure.

Felsite porphyrites in flows alternating with quartz porphyrites and tuffs, have a distinct porphyritic texture, with phenocrysts of albite and biotite. The crystals of the latter are either fringed with opacite or are completely opacitized. The felsite-porphyry groundmass consists of brown-yellow glass with a locally cellular, flow structure with a few discernible crystals of quartz and K-feldspar.

Felsite porphyrites are transitionally associated with lava breccias of quartz porphyrite, whose vitreous groundmass carries crystals of albite and biotite, and small, as much as 2 mm long, fragments of quartz porphyrites, more or less crystallized.

Rocky ridges near Korsakovo, along the left bank of the Amur, are formed by volcanic quartz porphyry breccias consisting of angular fragments of light gray, yellowish to pinkish quartz porphyrites, more or less crystallized and cemented with a violet-gray, vitreous groundmass. The groundmass has a flow structure and is filled with very fine angular fragments of albite and biotite, with fairly common pyrite grains. The character of the Korsakovo volcanic breccias suggests the proximity of a volcanic center, the source of all these acid lavas.

In the Nora Valley, the acid flows (of quartz porphyrites and their tuffs) are transitionally associated with the hypabyssal varieties of quartz porphyrites exposed in the river bank. The same is present in the right bank area of the Magdagacha, in the upper Amur basin.

CONCLUSIONS

It should be emphasized, in conclusion, that the upper Amur extrusive sequence is a fairly complex formation, both in its composition and the manner of occurrence. It was formed as a result of multiple volcanic eruptions of a fracture and central type, accompanied by lava flows and pyroclastic formations.

The composition of this volcanic complex, with the maximum thickness of about 1,500 m, changed gradually in the course of the process, from more basic in the lower part to intermediate in the middle part, and to acid in the upper part of the section.

In the lower part, extrusive and pyroclastic formations alternate with sedimentary rocks: conglomerates and sandstones with a considerable addition of tuffaceous material. The presence in tuffaceous sandstones of poorly preserved imprints of land plants, together with certain peculiarities of the extrusive flows (intensive opacitization of biotite, etc.), leads to the belief that the accumulation of volcanic material proceeded under continental conditions.

A close relation, both spatial and structural, has been observed in many extrusive areas, between upper Mesozoic granitoids and individual volcanic formations. This is especially true for upper Mesozoic hypabyssal basic, intermediate, and acid bodies which are the exposed roots of extrusive and pyroclastic rocks of corresponding composition.

There are a number of exposures showing a gradual transition from hypabyssal granodiorite porphyrites, porphyrites, and quartz porphyrites to sheets with corresponding composition and with flow and pyroclastic features. These point to a close genetic relation of hypabyssal upper Mesozoic rocks with the extrusive sheets.

The age of these volcanics is determined from the stratigraphic relationship of its component rocks with other sequences of the upper Amur region, which have been fairly characterized. The extrusives rest on various Middle and Upper Jurassic and Lower Cretaceous beds, identified from their flora, and on intrusive granitoid bodies which cut them. The upper boundary of this extrusive complex is represented by unconsolidated Tsagayan deposits whose age, from their plant remains, has been determined as Senonian-Danian to Oligocene; and the age of our extrusive complex, as Upper Cretaceous (pre-Senonian to Danian).[3]

In its composition and structural position, the upper Amur Upper Cretaceous extrusive complex is similar to that of the eastern Trans-Baikal region, of an Upper Jurassic age. It is of interest that those extrusives proceed from more acid to basic, i.e., in a reverse order from the eastern Amur region Upper Cretaceous volcanics.

A "rejuvenation" of the thick volcanic formations seems to take place, going from west to east; and with it, a uniform change in their sequence and composition.

[3] In addition, there are Cenozoic (post-Tsagayan) basalts, in the upper Amur region. Their stratigraphic relationship with the Upper Cretaceous volcanic complex was observed in a number of places, by A. Z. Lazarev, in 1950; by N. A. Bogdanov, in 1956, and by others. However, Cenozoic basalts of the upper Amur region require a special study and have not been considered in this paper.

Geologic Institute,
Academy of Sciences, U. S. S. R.
Moscow.

Received March 26, 1958

CERTAIN STRUCTURAL FEATURES OF PRECAMBRIAN METAMORPHICS OF THE KURSK MAGNETIC ANOMALY (K.M.A.), THEIR CAUSES AND STRATIGRAPHY SIGNIFICANCE[1]

by

N. A. Plaksenko

After an analysis of possible causes for a regular alternation of rocks in a standard section, the author separates two main facies in the middle division of the K.M.A., a magnetic and a hematitic. Their description and the distribution areas within the northeastern K.M.A. belt are given.

* * * * *

The author took note of structural features of the K.M.A. metamorphics in various places, in his study of cores and cuttings from numerous boreholes [2].

Locally the Precambrian is divided into three stages: the upper limestones and shales; the middle ferruginous quartzites (divisible into beds); and the lower schists and gneisses.

We shall concern ourselves mostly with the ferruginous quartzites.

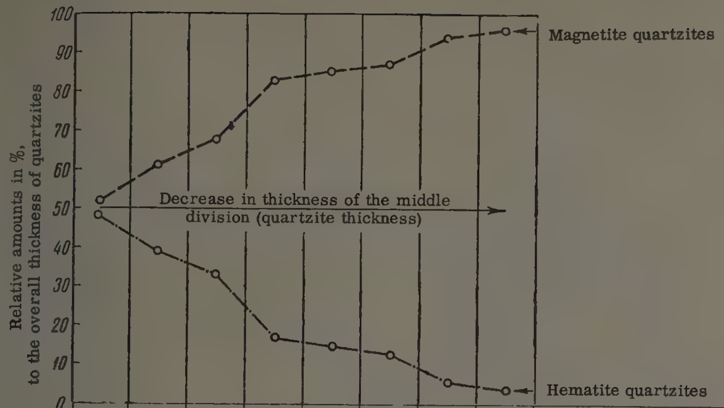
1. In those K.M.A. Precambrian areas where the middle division is 200 m thick or less, the ferruginous quartzites are represented by magnetite varieties, with little or no hematite at all. Conversely, where the middle division is more than 200 m thick, much of it is represented by hematite-carrying (hematite-magnetite) quartzites. This pattern is graphically illustrated in Figure 1. Thus, the middle division is about 500 m thick in the Tim district, and the hematite and magnetite (now martite) quartzites are almost equally developed. In the Stoylo-Yastrebovka area, on the other hand, the middle division decreases to 120 to 140 m, and magnetite predominates in the quartzites (94 to 96%, with 4 to 6% hematite quartzites). These qualitative ratios are related not only to the thickness of the entire quartzite sequence but to the number of metashale beds in it. The decisive factor appears to be not so much the thickness of the metashale beds, measured in meters, but their number, i.e., the frequency of the alternation of metashales and quartzites.

It has been established that beds and zones of hematite-carrying (hematite-magnetite) quartzites, in all cases, contain a few very thin metashale intercalations. Conversely, the maximum number of metashale beds and lentils is concentrated in beds of magnetite (hematite-free) quartzites, with the metashale beds attaining tens of meters. These two types of quartzite differ not only in the number of more or less thick metashale beds but also in the overall content of silicate minerals in very fine individual intercalations and in crystals and aggregates in ore and quartz intercalations. This determines the difference in the Al_2O_3 and silicate iron content in magnetite and hematite-magnetite quartzites and the high content of these components in magnetite quartzites (Figs. 2 and 3). The content of Al_2O_3 and silicate iron in the quartzites increases with the decrease in the relative amount of magnetite and with the increase in hematite. The minimum quantites of these components are characteristic for those quartzites that are the richest in hematite.

The amazing similarity of the curves in both diagrams, and of the average values of the amount of Al_2O_3 and silicate iron for quartzites with definite magnetite-hematite ratios, is possibly indicative of the relationship between the main body of silicate iron in quartzites with the aluminum bearing mica minerals, i.e. with the metamorphic products of the original pelitomorphic sediments rather than with ferromagnesian amphiboles which originate to a considerable extent in the metamorphism of ferrosiliceous sediments.

2. Where hematite-magnetite quartzites are present in the quartzite sequence, they occur in the central part of the middle division, or at least within it rather than on its periphery, and are separated from the upper

[1]O nekotorykh osobennostyakh stroyeniya tolshchi metamorficheskikh porod dokembriya kma, prichinakh ikh voznikoveniya i ikh stratigraficheskom znachenii.



477	More than 300	More than 250	210–220	242	200	123	143	Thickness of middle division, in m
Tim	Korobkovo	Saltykovo	Shchigry	Oskoletz	NE Korobkovo	Sloylo	Yastebovka	Locality

FIGURE 1. Relationship between the quantitative ratios of magnetite and hematite quartzites and the overall thickness of their sequences in some K.M.A. areas.

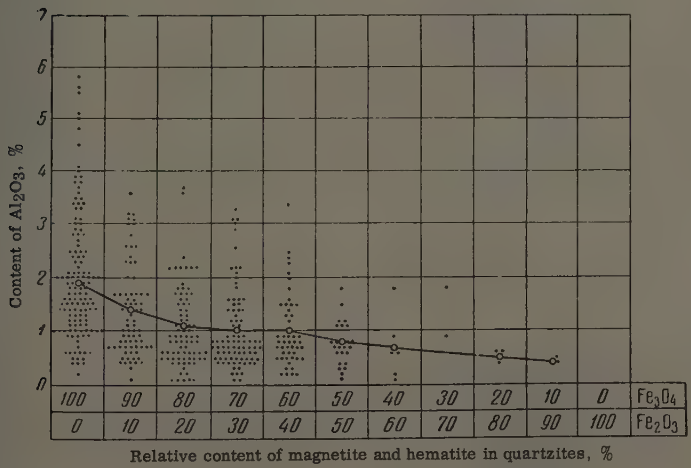


FIGURE 2. Relationship of the Al_2O_3 content and the magnetite-hematite ratios in the K.M.A. ferruginous quartzites (from 467 analyses).

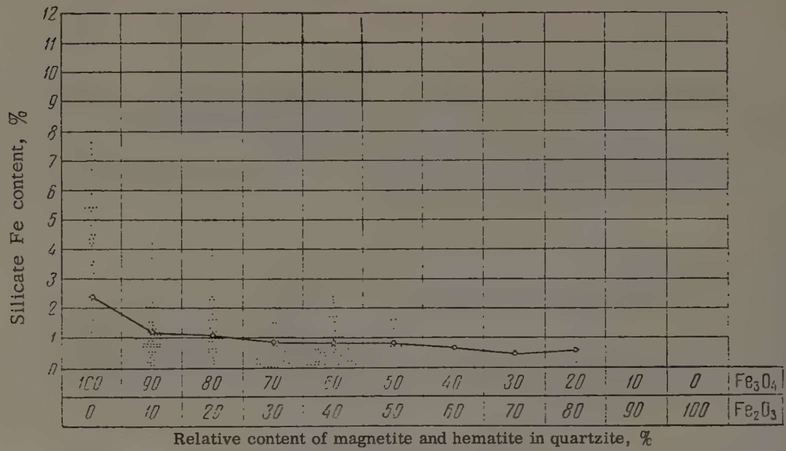


FIGURE 3. Relationship between the magnetite-hematite ratio and the silicate iron content in the K.M.A. ferruginous quartzites (from 647 analyses).

and lower divisions by beds of magnetite (hematite-free) quartzites, with or without amphiboles. Generally, the position of hematite and other quartzites in a standard middle division section is as shown in table below.

The middle division may contain more than one hematite-magnetite bed, in which event they alternate with magnetite quartzite beds, occupying an interior position in the sequence. With an intensive development of ferromagnesian amphiboles in quartzites, such quartzites may directly contact the hematite-magnetite quartzites, without a separating layer of amphibole-free varieties.

This feature of the quartzites stands out clearly in correlations of the middle division sections from various K.M.A. localities.

3. In ferruginous quartzites consisting of both the magnetite and hematite-magnetite varieties, and containing beds and intercalations of metashales, a regular alternation of the ferruginous quartzites has been observed between the successive metashale beds, if the latter be accepted as the boundaries of the given interval. Directly contacting the metashale beds are magnetite (hematite-free) quartzites. Usually present on both (less commonly on one) sides of a metashale bed (on top and at base), between it and the magnetite quartzite, are layers of poorly mineralized and, in many places, pyritized and carbonatized magnetite quartzite. A central bed of hematite quartzites is located in the

Upper division rocks	
Middle division rocks (chiefly quartzites)	Amphibole-magnetite [a] Magnetite Hematite-magnetite Magnetite Amphibole-magnetite
Lower division rocks	

[a]Rocks containing ferromagnesian amphiboles: cummingtonite-grunerite, tremolite, actinolite.

middle of the interval. In other words, if two metashale beds are taken for the boundaries of an interval containing both the magnetite and hematite-magnetite quartzites, the magnetite quartzites will enclose the hematite varieties. Thus, each unit repeats the Precambrian sequence of major Precambrian stratigraphic units, in certain K.M.A. areas (Fig. 4).

It is significant that the superposition of alkali metasomatism (the appearance of alkali amphiboles and pyroxenes) does not change the position of magnetite and hematite-magnetite quartzites among the over- and and underlying Precambrian rocks of the middle division as a whole, and between the successive metashale beds. This suggests, to some extent, that the alkaline metasomatism most likely was not accompanied by newly formed hematite in amounts sufficient to sharply alter the diagenetic and metamorphic ratio of hematite and magnetite in the quartzites. Otherwise, hematite would have originated, along with alkaline amphiboles, in the magnetite quartzites adjoining the metashales which is not the case. The quartzites have only been enriched in amphiboles and pyroxenes.

To be sure, hematite quartzites are not always present between metashale beds, separated from them by magnetite quartzites. In some places, only the magnetite quartzites have been found between the metashale beds. This exception, as we shall see, is not unusual and fits well into our concept of the sedimentation of the K.M.A. metamorphic complex.

4. Like the quartzite-metashale boundary, the boundary between the ferruginous quartzite division and the enclosing rocks, provided there is no obvious tectonic or erosional break in between, is marked by a transition, always thin, of usually poorly to not-at-all mineralized, commonly micaceous (and amphibolitic), pyritized and carbonatized quartzites or dark biotite-carbonate-pyritic rocks. This siliceous or carbonate-sulfide layer marks a transition from ferrosiliceous to pelitomorphic sediments (shales).

These are the general structural features of the K.M.A. Precambrian ferruginous quartzites. It is believed that they sufficiently clearly reveal the great effect of the primary properties and features of sedimentary rocks on the subsequent processes of alteration and the formation of the K.M.A. metamorphics.

What is the origin of this regularity in the alternation of a specific metamorphic bed in the K.M.A. Precambrian sequence? Are all these features (especially the regular distribution of hematite and magnetite quartzites) a result of subsequent metamorphic (including the retrograde) and metasomatic (including the additive) processes which have obliterated the primary rock characteristics, or were they, on the whole, inherited from the source sediments?

The answer is important in its bearing on the position of the hematite-magnetite quartzites, because it is here that geologic opinion has been most widely divided.

The local possibility of the formation of some hematite (for instance, in alkaline amphibole quartzites) in the process of retrograde metamorphism is not fully rejected. Such phenomena do take place, here and there, although the presence of such metamorphism, and its part in the formation of the present metamorphic rocks (chiefly quartzites), are far from being certain. We believe, however, that the pattern in the position of hematite quartzites in the metamorphic sequence has been produced by sedimentary processes which determined the qualitative differences in the orignal sediments at different stages. Such sediments would result in metamorphic rocks of different compositions (including the ore minerals), even under the same metamorphic conditions. It is also quite clear that even where the so-called "retrograde" hematite is present, the conditions of its occurrence, its form, structure, and textural relationship in quartzite cannot be those emerging from the progressive metamorphism of original ferrosiliceous rocks. Indeed, they differ greatly from the latter. Thus, any possibility of mistaking these two hematite forms in the study of quartzites is out of the question, let alone mistaking their part in the formation of ferruginous quartzites. The scope of the "retrograde" hematite is so small as to locally preclude the effect of such hematite on the primary metamorphic composition of ferruginous quartzites. We shall now attempt to determine the most characteristic properties of the original sediments, which most affected the above-stated relative position of various quartzites and metashales, and the origin of these properties.

Figure 5 presents the most typical alternation from the data of Figure 4 of the regular alternation of principal metamorphic varieties within the middle division: metashales, magnetite quartzites, and hematite-magnetite quartzites.

Schistose beds and intercalations within and without the ferruginous quartzites are represented chiefly by biotite phyllites and more or less metamorphosed biotite and other less common schists. In their origin, they are metamorphosed argillaceous terrigenous near-shore deposits. Schistose layers

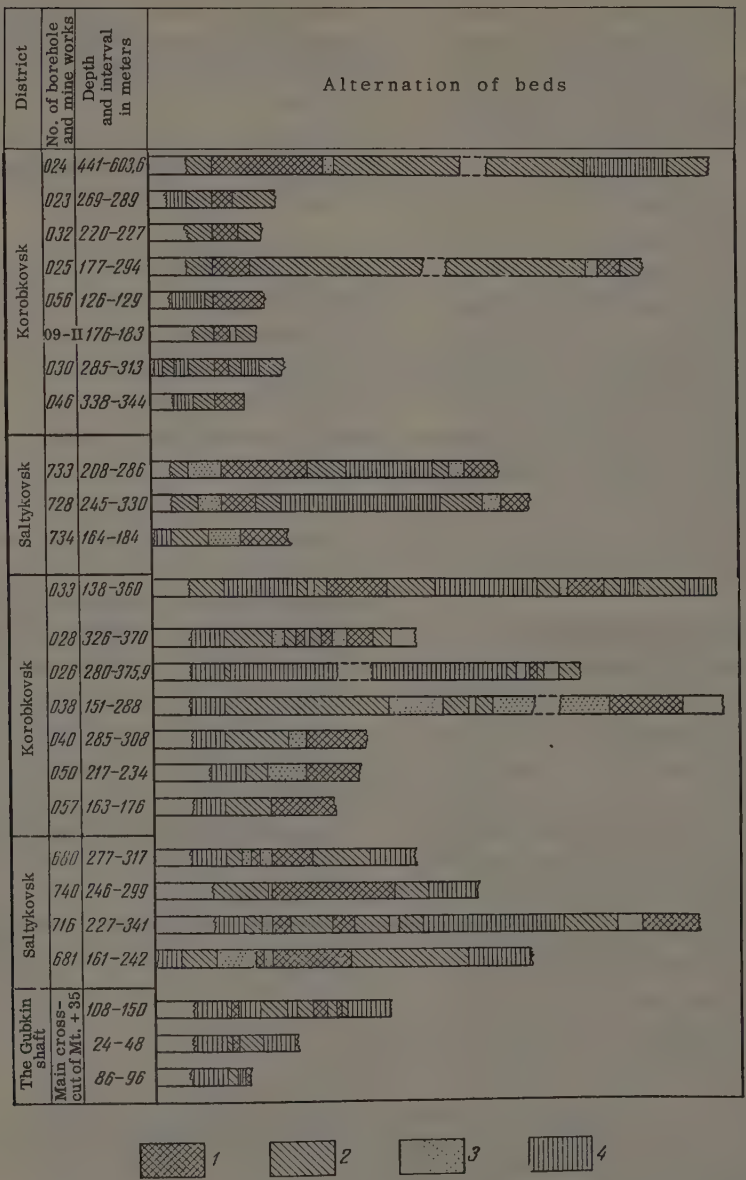


FIGURE 4. Some characteristic features of the alternation of various types quartzites and metashale intercalations in a standard K.M.A. Precambrian section. The nature of the intervals is illustrated by columns opposite their lengths. The table is not to scale.

1 -- metashales, chiefly biotite; 2 -- barren quartzites; 3 -- magnetite quartzites including the alkaline amphibole-magnetite; 4 -- hematite-magnetite quartzites, including the alkaline amphibole varieties.

among ferruginous quartzites commonly carry rounded clastic grains of quartz and other minerals. Thus, they are metamorphosed shallow argillaceous terrigenous deposits.

Farther up, away from the metashale, there is a bed of barren quartzite. Its thickness locally decreases to a few centimeters, the decrease taking place on both sides, in few examples on one (chiefly at the base).

The magnetite quartzites lie in beds, either on barren quartzites or directly on metashales, with either a sharp or gradual contact (Fig. 5). They are coarser grained, with well defined to sharp boundaries between the ore bearing and quartzite layers, and with larger magnetite crystal aggregates as compared with hematite. The magnetite quartzite beds carry considerably more numerous beds and intercalations of metashales i.e., the terrigenous material, and are characterized by a higher content of alumina and silicate iron than in the hematite-magnetite quartzites.

Finally, magnetite-quartzite of some areas where the middle division is thin and contains a considerable number of metashale layers (Yastrebovo, Stoylo) contains chainlike bedding, locally massive (in lentils) accumulations of rounded apatite grains, most likely clastic.

From all these data, the hematite-free quartzites may be regarded as metamorphic products of a peculiar ferrosiliceous sediment, formed chiefly from iron in suspension and from a terrigenous argillaceous and siliceous material, considerably enriched in organic matter, with a somewhat lower content of colloid iron and silicon. The formation of this sediment occurred under low oxidation conditions.

The position of magnetite quartzites with relation to the metashales in a standard middle division section suggests that the source sediments of these magnetite quartzites were deposited in a deeper littoral zone (Fig. 5), i.e., during a transgression. The sedimentary conditions and the qualitative features of this material, along with its structure and texture, determined its alteration to quartzite, other metamorphic conditions being equal.

Finally the central member of the regular series, which was superposed on magnetite quartzites, upward from the metashales, is represented by hematite-magnetite or magnetite-hematite quartzites with the following characteristics: a fine-banded texture or an internal fine banding in ore and quartz layers; a less distinct contrast between ore (hematite and hematite-magnetite) and quartzite bands; an association of hematite with finer-grained quartz, as compared with magnetite; finer aggregates and crystals of hematite as

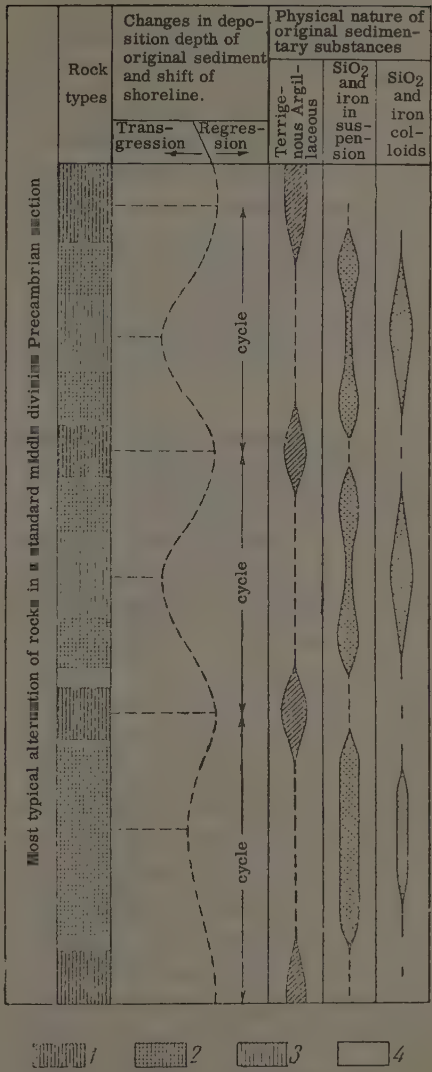


FIGURE 5. Relationship between the mineral composition of the K.M.A. Precambrian metamorphics and their position in the standard section, on one hand, and the character of the source sediments, as determined by a shift in the shore line and the change in depth, on the other.

1 -- metashales; 2 -- magnetite quartzites; 3 -- hematite quartzites; barren and poorly mineralized quartzites.

compared with magnetite; finally, a greater homogeneousness of quartzite and a very small number and thickness of the metashale intercalations, i.e., of terrigenous material, and the resulting very low content of alumina and silicate iron.

These features of hematite quartzites, their texture and structure, and the relationship between their hematite and magnetite, suggest that their primary ferruginous and siliceous substances were deposited chiefly as colloids, separately but generally simultaneously. The specific sedimentary conditions of primary ferruginous and siliceous colloids, and their differentiation in sedimentation, are responsible for the corresponding structural and other features of the deposits, which determined the preservation of hematite along with the magnetite in quartzite during the process of metamorphism.

As long as we assume that these substances were deposited chiefly as colloids, and mostly simultaneously, this alone determines to a certain extent the place and the deposition conditions for hematite-magnetite quartzites. Colloid iron, in a sedimentary basin, is known to be deposited at a lower rate than iron oxide in a mechanical suspension. The settling of colloid iron particles is, in addition, uneven, depending on the size of the gel aggregates. Larger clots settle faster and, consequently, nearer to shore, whereas the smaller coagulations remain in suspension longer and are carried to more quiet, i.e., deeper, parts of the basin. If, at the same time, the iron colloids are mixed with those of silica, they are known to change their charge and remain noncoagulated, almost until the beginning of the silica hydrosols coagulation. The experiments of Moore and Maynard (1929) have established that the settling of SiO_2 at the action of electrolytes is extremely slow, lasting many months [1, 3]. In addition, the study by Corrence (1940) and Roy (1945) has shown that a SiO_2 solution in river and sea water is far from the saturation point and that this circumstance precludes chemical precipitation of SiO_2 at the junction of sea and river waters. Therefore, the precipitation of a certain amount of silica colloids and the associated iron colloids proceeds at some distance away from shore [3, 4]. In other words, the primary substance of hematite-magnetite quartzites was deposited in a deeper part of the basin than the substance of magnetite quartzites. This is what has determined the comparative homogeneousness of the hematite-magnetite composition and the lack in them of a large amount of metashales (terrigenous), and consequently of Al_2O_3 and silicate iron. Thus, the presence of hematite-magnetite quartzites among the Precambrian middle division magnetite quartzites indicates an intensified transgression, i.e., to a deepening of the basin.

Supplementary and, in our opinion, convincing data in the reconstruction of the character of the source materials of ferruginous quartzites and the conditions of their deposition are obtained from an analysis of the content and ratios of ore iron and silica in ferruginous quartzites as compared with those of magnetite and hematite.

The maximum and the average contents of soluble iron (ore) in ferruginous quartzites are in a definite relationship with the relative amounts of magnetite and hematite (iron scales) in them (Fig. 6). The purely magnetite quartzites (hematite-free, including the amphibole quartzites) are characterized by a widely fluctuating range of the soluble iron content, from ore-poor (15 to 20%) to rich (more than 35%). The average soluble iron content in them, from 1193 analyses, is 31%.

Such inconsistency in the soluble iron content for purely magnetite quartzite is related, in our opinion, to the facies features of the original sediments. As pointed out before, the purely magnetite quartzites are derivatives of the original ferrosiliceous sediments of the shallowest (in the K.M.A.) magnetite ferruginous facies, characterized by a large content of a terrigenous pelitomorphic material. It also has been noted that the presence of numerous metashale beds and intercalations, points to a comparatively frequent change in the character of the sediments because of the change in the depth.

Such instability of the facies is characteristic of a comparatively shallow shelf where even a small change in the depth is accompanied by an appreciable and even abrupt facies change. Evidently, this change in facies, accompanied by a change in the composition of the original ferrosiliceous sediments and by a constant addition of suspended terrigenous material, had its effect also on the distribution of ore iron in magnetite quartzites.

The situation is quite different for the soluble iron (ore) content in hematite (hematite-magnetite and magnetite-hematite) quartzites. It is noteworthy that the character of the iron-ore distribution (the range of its content fluctuation) in such quartzites, even with an insignificant hematite content (iron scales), differs radically from its distribution in magnetite quartzites. Thus, if the iron-ore content in purely magnetite quartzites is commonly decreased to 20% and lower, the soluble iron content in ferruginous quartzites with 10% hematite, relative to the sum of ore minerals, hardly ever drops below 31%, being more than 33% in most samples. The range of the content fluctuation of soluble iron in quartzites decreases on the whole,

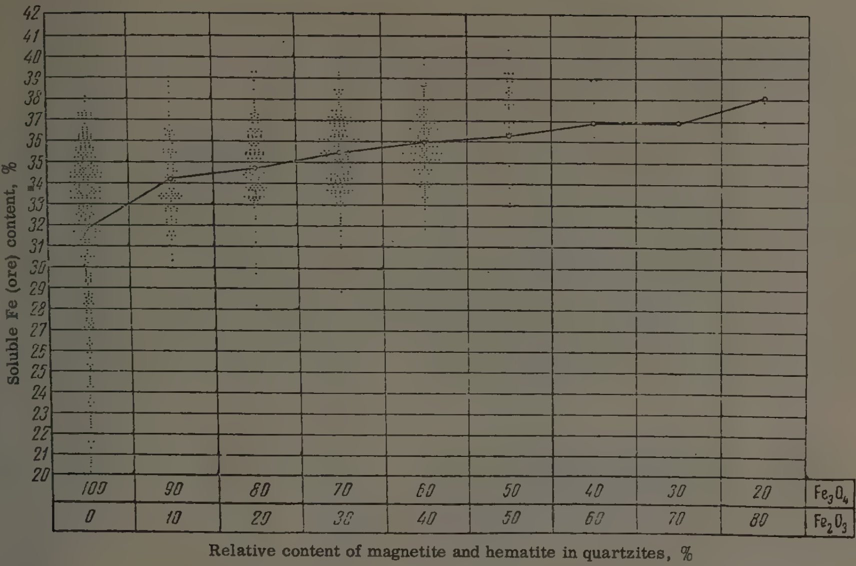


FIGURE 6. Relationship between the absolute content of soluble (ore) iron and the magnetite-hematite ratio in the K.M.A. ferruginous quartzites.

whereas its average content generally increases, with an increase in the relative hematite content. The change is most abrupt from purely magnetite quartzites over to the hematite-magnetite, with 10% relative hematite content. It becomes more gradual with a further increase in the hematite content.

The diagram (Fig. 6) shows that hematite-magnetite quartzites are characterized by a certain consistency in both the content fluctuation range and in the average content of soluble iron. As compared with magnetite quartzites, the hematite-magnetite quartzites are especially noted by the consistency of their lower limit of the soluble iron content. Disregarding the few noncharacteristic analyses, it may be stated that the latter hardly ever is below 33%, for hematite-magnetite quartzites, whereas the upper limit is somewhat higher than in the magnetite quartzites. Depending on the magnetite-hematite ratio, the average content of soluble iron in hematite quartzites varies from 34.25 to 38%.

The limit and amount of the silica content in ferruginous quartzites are also definitely dependent on their relative magnetite and hematite content. It is the increase in the relative hematite content that narrows the silica content range in ferruginous quartzites, whereas the content itself decreases consistently. In other words, ferruginous quartzites with definite magnetite-hematite ratios have a fairly definite average silica content (Fig. 7).

In comparing these two patterns in the change of the silica and soluble iron contents in quartzites, depending on the change in their hematite-magnetite ratios (Fig. 8), we find that the ratios of the average contents, or the molecular amounts of silica, to the soluble iron in quartzites with definite magnetite-hematite ratios, are constant. In other words, quartzites with definite relative amounts of magnetite and hematite are marked by quite definite ratios of both the average contents and the molecular amounts of silica and soluble iron.

For instance, the ratios of the molecular amounts of silica and ore iron change from 1.45 to 1.15, from the purely magnetite quartzites to those with equal relative amounts of magnetite and hematite (50% for each). Fig. 8 presents two curves of the relative content for soluble iron. The solid line has been constructed from the same analyses as the average silica content curve, above. The dashed line is, in part, the curve of Figure 6, constructed from other data. The amazing, nearly full coincidence of these two curves confirms the validity of the patterns.

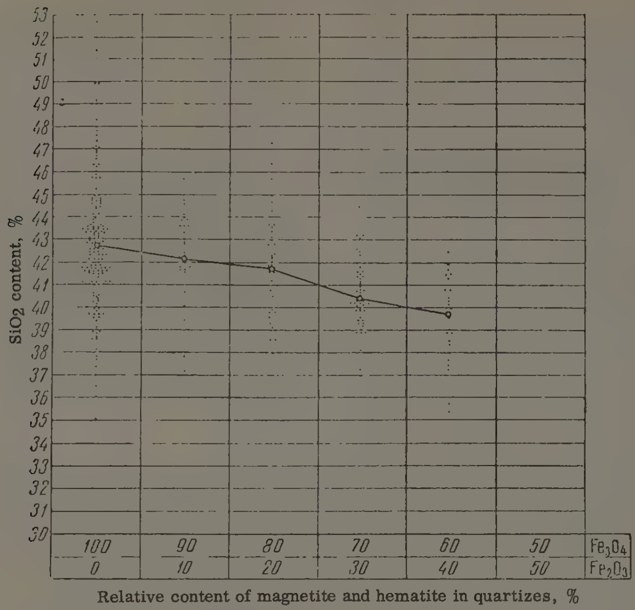


FIGURE 7. Relationship between the silica content and the magnetite-hematite ratio in the K.M.A. ferruginous quartzites (from 373 analyses).

1.35	1.24	1.21	1.14	1.08		Ratio of average contents SiO_2/Soluble Fe
1.45	1.32	1.3	1.2	1.15		Ratio of molecular contents SiO_2/Soluble Fe

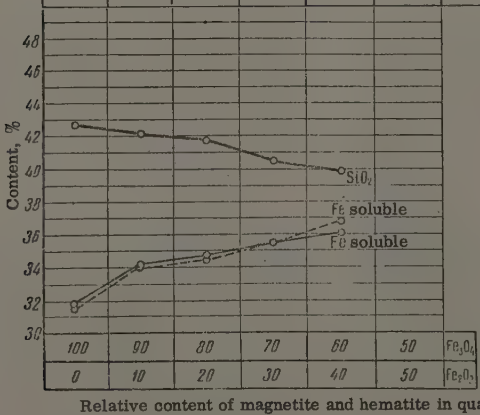


FIGURE 8. Relationship between the SiO_2 and soluble iron contents in ferruginous quartzites and their hematite-magnetite ratios.

The consistency in the distribution of soluble iron and silica in hematite-magnetite quartzites may be indicative of a fair degree of purity of the original ferrosiliceous colloids, of an adequate facies stability during the sedimentation, and of relatively consistent ratios between the colloids of silica and iron, which promoted their maximum combined and individual coagulation and deposition.

N.M. Strakhov [3], on the basis of V.N. Simakov's work, points out that the maximum precipitation of iron and silica colloids from their mixture takes place with the ratio of the molecular amounts for silica and soluble iron in the 1.0 to 1.6 range. These figures almost coincide with our values and again suggest that hematite-magnetite quartzites were originally deposited in a quieter and deeper segment of the shelf, than were the magnetite quartzites, and that the magnetite-hematite ratios were established as early as during the precipitation of their primary ferruginous and siliceous colloids, being determined by the molecular ratios of silica and hydroxides of iron (iron ore) in a mixture of their sols. It appears that these ratios have remained almost intact in the metamorphic process.

The existence of this silica-iron ore relationship as a function of the relative amounts of magnetite and hematite is an inherited evidence of the regularity in the deposition of ferrosiliceous colloids. This relationship would not exist if one of the ore minerals had not been associated with the primary sedimentary process but was of a late origin, such as metasomatic.

It is, then, certain that this and other features of the distribution of certain chemical components and principal ore minerals in ferruginous quartzites have been inherited from the original sediments.

The alternation of rocks throughout the section is as follows:

The hematite quartzites are overlain by magnetite quartzites, then by metashales, and the order is repeated. In other words, the rock alternation from the middle of the deposition period for one shale bed to that of the next one presents a sort of separate sedimentation cycle. Each such cycle opened with a maximum sea regression (terrigenous material -- metashales), went through a transgression (ferruginous suspension load, colloids, terrigenous material -- magnetite quartzites), to its maximum (colloids and suspension -- hematite-magnetite quartzites), and back to a maximum regression, expressed in the deposition of the next shale intercalation. To be sure, the proportion of terrigenous material, of the mechanical suspension, and of colloids in the body of deposits changed considerably throughout the sedimentary stages (cycles); i.e., each sedimentary cycle and its deposits differ, more or less, from the preceding cycle and its sediments. Therefore, any of the three principal components -- terrigenous material, mechanical suspension, or colloids -- may be almost totally missing in the alternating middle division cycles; and with them, the resulting metamorphics: metashales, magnetite quartzites, and hematite-magnetite quartzites. Thus, there is no closed circle of phenomena, here, but rather an unquestionable objective regularity in the development of sedimentary processes, where similar conditions bring about a similarity in the primary deposits. It is natural that qualitatively similar primary deposits produce similar rocks, as a result of the same metamorphic process, and vice versa.

On the basis of these data and of the results of study of genetic relationship between hematite and magnetite in ferruginous quartzites, it is believed that those features of primary siliceous and ferruginous deposits, determined by the depth, the character of sedimentation, and the nature of the primary substances, were the main factors in the formation of ferruginous quartzites, different in the nature of ores. Different primary forms of iron (ferruginous suspensions and colloids with oozes and organic matter; pure colloids of iron and in a mixture with silica), subjected to the same metamorphic process, resulted in different end forms. The more shallow ferruginous deposits (chiefly from suspension), with an addition of ooze and organic material, deposited and altered diagenetically under low oxidation conditions, were metamorphosed to magnetite quartzites. The deeper and purer ferruginous sediments (chiefly iron colloids in a mixture with silica colloids) became hematite-magnetite or hematite quartzites.

The lack of hematite-magnetite quartzites between the metashale beds, in some intervals, and their nearly total lack in the middle division as a whole, in some localities, suggests that transgression gave place to regression at times, before the basin had attained the optimum depth for the deposition of the iron and silica colloids, which were the ancestors of hematite-magnetite quartzites.

It is, therefore, beyond doubt that these alternation patterns of the K.M.A. Precambrian metamorphics have been conditioned by the original sediments, by the periods of transgression and regression, and the change in the basin depth and the corresponding sedimentary conditions (Fig. 5).

We see, then, a general sea transgression contemporaneous with the deposition of Precambrian rocks of the iron ore-bearing

middle division. On this background, minor and comparatively short oscillations of the earth's crust took place, not accompanied by sedimentary breaks but responsible for a certain change in the deposition depth and for fairly sharp facies changes, from typical terrigenous (shales) through intermediate terrigenous-colloid (magnetite quartzites with thin metashales) to typical colloids (hematite-magnetite and hematite quartzites-jaspilites). Accordingly, the observed alternation of these rocks in the K.M.A. standard Precambrian section may be regarded as a stratigraphic phenomenon.

This conclusion is of great moment in the study of magnetite and particularly of hematite-magnetite quartzites, because of the controversy as to their origin and the causes of their parallel occurrence. Because of the lack of information, some geologists do not take into consideration the scope of the phenomena under study, resulting in erroneous deductions.

From the alternation of various rocks (Fig. 5) throughout the middle division, a reconstruction of the alternation pattern is attempted for the original sedimentary facies. In Figure 9, I-V are the sedimentary stages; stages I-III are transgressive; stages IV-V, regressive. The deposits corresponding to each stage are designated by corresponding Arabic numerals. Thus, the change away from the shore proceeds as follows: terrigenous argillaceous material; ferruginous

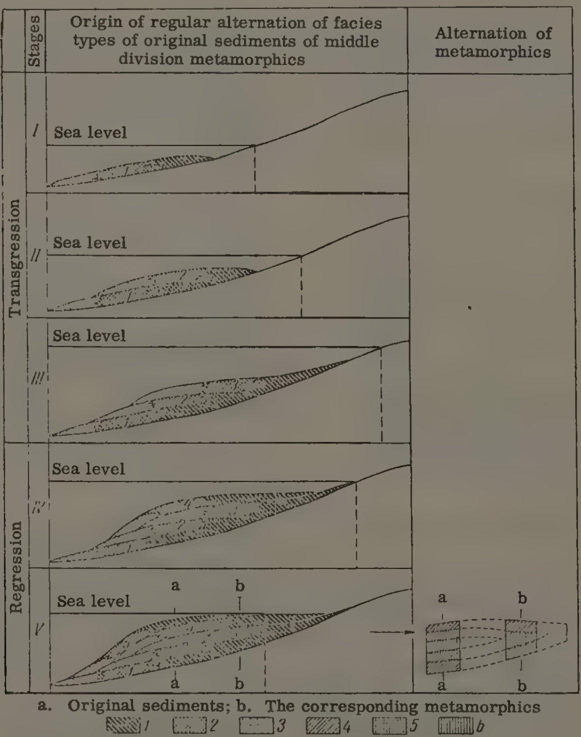


FIGURE 9. The origin of the regular alternation of facies in the original sediments of the K.M.A. middle division Precambrian rocks.

1 -- terrigenous argillaceous material; 2 -- ferruginous suspension, with less terrigenous material and with iron and silica colloids; 3 -- iron and silica colloids, with less ferruginous suspension and terrigenous material; 4 -- shales; 5 -- magnetite quartzites with shale intercalations; 6 -- hematite quartzites.

suspension with terrigenous material and colloids, the colloids being chiefly of iron and silica. Accordingly, the alternation of transgressions and regressions (change in the depth of deposition) produces the vertical and lateral changes in the primary facies, as shown on the diagram. Such a scheme is in agreement with the observed alternation in the K.M.A. Precambrian metamorphics.

An analysis of this scheme reveals the magnitude of the effect of the nature of original sediments and the conditions of their deposition on the course of the subsequent formation of metamorphic rocks, chiefly of magnetite and hematite-magnetite quartzites, and consequently on their present stratigraphic position.

All these changes in the sedimentary conditions responsible for the sedimentary features, appear to have had a considerable range. Most likely, they took place in the shelf zone, including its lower part and possibly the beginning of the continental slope [3].

Figure 9 clarifies the central (middle) position of hematite-magnetite quartzites in the middle Precambrian division as a whole, and between the metashale intercalations in particular. It also explains the regular decrease in number and thickness of metashales (terrigenous material), away from magnetite quartzites and toward the hematite quartzites. The amount of suspended argillaceous material and the size of its particles decreases with depth, in the direction of the deposition of primary colloids resulting in the present hematite-magnetite quartzites.

It is also obvious that, in the subsequent metamorphism, the primary features of sediments did determine the specific effect of altering solutions.

A generalized structural outline of the northeastern part of the K.M.A. middle division (Fig. 10) gives an even better idea of

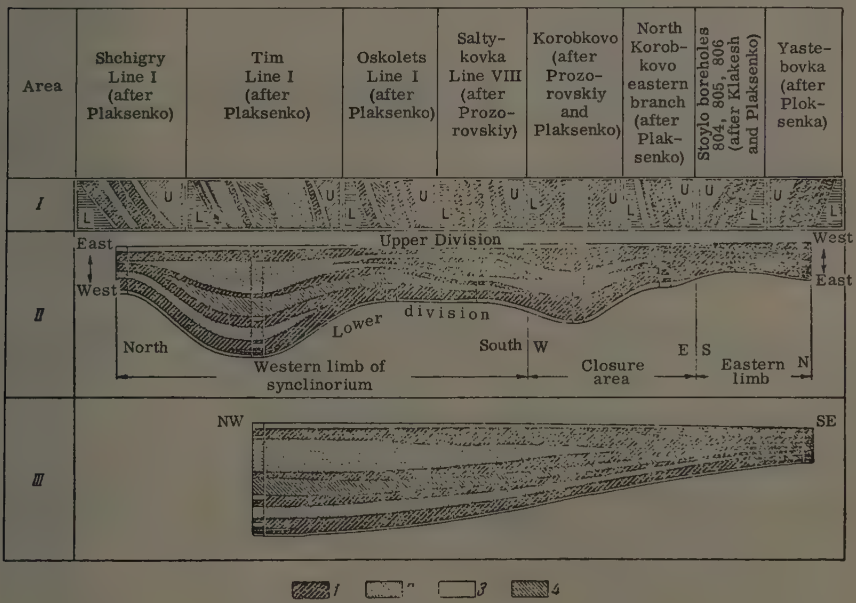


FIGURE 10. Composite structural plan for ferruginous quartzites of the K.M.A. Precambrian middle division.

I -- observed surface position; II -- standard columns of the middle division and a composite cross section, from drilling data, along the synclinorium axis, parallel to the assumed shoreline; III -- a standard section across the synclinorium, along line Tim-Yastrebovka (middle division facies change).

1 -- magnetite quartzites, including the amphibole-magnetite; 2 -- hematite-magnetite quartzites; 3 -- barren and ore-poor quartzites, including the amphibole; 4 -- metashales in quartzites; B -- upper division rocks; H -- lower division rocks.

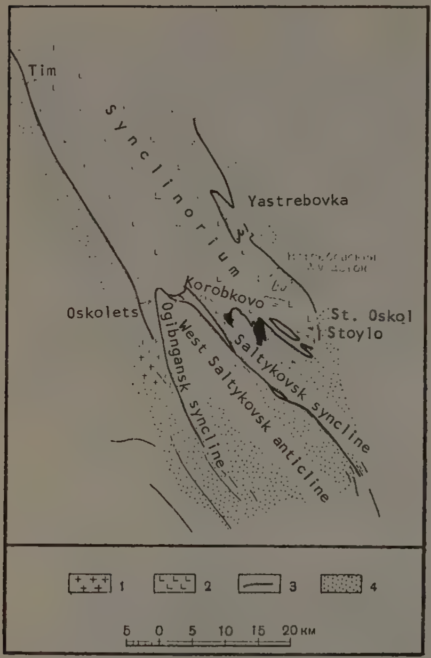


FIGURE 11. Structural map of the northeastern K.M.A. belt.

1 -- intrusive rocks; 2 -- upper division; 3 -- middle division (thickness not to scale); 4 -- lower division.

the importance of the primary ferruginous facies in the formation of the present K.M.A. quartzites, and of the enormous stratigraphic significance of the observed structural patterns in the latter. A structural map of the northeastern K.M.A. area (Fig. 11) clarifies the areal facies changes.

The surface outcrops and a cross section of the synclinorium, parallel to its assumed shoreline, reflect the relationship and distribution of the middle division facies, vertically and laterally, depending on the depth of the basin. The section across the synclinorium clearly shows the change in the primary facies, from the west (Tim) to the east (Yastrebovka) limb -- from deeper to shallower facies -- and the corresponding composition changes for ferruginous quartzites.

It may be stated, than, that two primary oxidation facies, a magnetite and a hematite, are present in this area of a comparatively shallow water K.M.A. Precambrian middle division. The deeper reaches appear to be located between the northeastern and southwestern zones. This author has no knowledge of them. In the area under study, the areal distribution of primary facies, away from shore, is as follows: shale (terrigenous facies) → magnetite facies → hematite facies (Fig. 12). It should be kept in mind that the hematite K.M.A. facies is not pure but transitional, and its quartzites carry much magnetite rather than hematite alone. Only such lateral alternation of primary facies could determine the observed vertical alternation of the corresponding rocks.

Characteristic features of the primary oxides in the K.M.A. middle division ferruginous quartzites are listed in Table 1.

Of interest are some observations of the American geologist H. James [5] on the origin of the Lake Superior ferruginous formations. They are pertinent to the extent of their being in direct contradiction to our conclusions on the spatial alternation of ferruginous oxide deposits (magnetite and hematite).

It is to be remembered that Van Hise, Leith, and other students of the Lake Superior ferruginous formations believed that its original composition had been represented by chemically precipitated ferruginous carbonates (siderites) and silica.

H. James divides the Lake Superior Precambrian ferruginous formations into four principal facies, on the basis of their original ferruginous minerals: the sulfide, carbonate, silicate, and oxide (Fig. 13). Most stable are

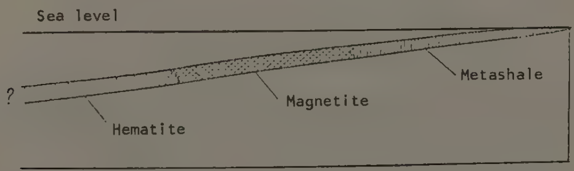


FIGURE 12. Sedimentary facies of the part of the K.M.A. Precambrian section studied.

Table 1

Characteristic features of the oxide facies of the K.M.A. ferruginous quartzites

Features	Primary oxide facies	
	Magnetite	Hematite
Lithology	Thin-banded and heterogeneously banded dark-gray rocks, formed from an alternation of quartz, magnetite, silicate, and more or less carbonatized layers. These rocks carry a considerable amount of metashales.	Thin-banded and heterogeneously banded (usually red-banded) rocks, formed from an alternation of quartz (sometimes jasper-like), magnetite, hematite, hematite-magnetite, less commonly silicate and carbonatized layers. These rocks are fairly homogeneous, with a few metashale intercalations.
Argillaceous rocks	Magnetite quartzites	Hematite-magnetite quartzites.
Basic ferruginous material	Magnetite	Magnetite and hematite
Range of the soluble iron content	Wide content range, less than 10 to 15% to more than 35%; average, about 31%	Narrow content range, from no less than 33 to 40%. The average, 34 to 38%, depending on the magnetite-hematite ratio.
Al_2O_3 content	0.2 to 0.7; more commonly 1.4 to 1.9; average, 1.6%	0.3 to 3.7%; more commonly 0.3 to 1.1%; average 0.7%
Range of SiO_2 content	Wide range, 35 to 53%; average about 43%	Narrower range, from not more than 48% to 35%; the average, 42 to 40% and less, depending on the magnetite-hematite ratio
Silicate Fe content	0.0 to 11.0%; more commonly, 1.2 to 2.4%; average 1.7%	0.0 to 1.1%; more commonly 0.4 to 1.1%; average, 0.7%
Stratigraphic position in the standard Precambrian section	Peripheral (with relation to quartzites), in the presence of the hematite facies	Within the quartzites
Areal distribution in the middle division	Nearly always building up thin sequences of the middle division	Best developed in the areas of a thick middle division
Principal physical state of the original ferruginous material	Mechanical suspension; less commonly as colloids	Iron and silica colloids, usually in a mixture
The sedimentary environment	With regard to the hematite facies, more shallow, intermediate oxidizing-reducing. Higher organic content; lower Eh	With regard to the magnetite facies, deeper, intermediate oxidizing-reducing. Lower organic content, higher Eh

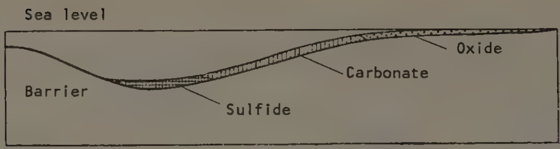


FIGURE 13. Sedimentary facies of the ferruginous formation, after H. James [5].

the sulfide, carbonate, and oxide, with the silicate facies, according to James, not having a fixed position in the section but somewhat shifting at the boundary of the reducing and oxidizing zones. H. James splits the oxide facies into two; one, characterized by magnetite and the other, by hematite. He states that both minerals appear to be primary sedimentary. Assuming further that ferruginous rocks of the oxide deposits originated under weakly oxidizing or moderately reducing conditions, he admits that the manner of deposition of magnetite is not quite clear. The hematite facies, according to H. James, was accumulated under intensive oxidation conditions, probably not far from shore. He believes that magnetite was diagenetically deposited as such and he thinks it unlikely that it could have been formed from other ferruginous minerals, in the metamorphism of silicates, carbonates, and hematite, because these minerals are commonly associated with magnetite. According to him, magnetite is a deeper oxide facies than hematite and is located between the latter and the carbonate facies.

However, H. James gives no specific cross sections to support his contention of the lateral distribution of his facies, which precludes verification. Nor does he give a comprehensive analysis of the process of ferruginous accumulation within the oxide facies. As a result, the formation of hematite and magnetite of this facies is ascribed solely to the effect of an oxidation-reduction environment, without any consideration given to the qualitative feature of the incoming ferrosiliceous substances, to the character of their associations, and to the quantitative and qualitative transformations in the process of sedimentation. It is well known that all these factors are no less important in the formation of sediments than the character of the environment. Still, the recognition by H. James of four primary sedimentary facies in Precambrian ferruginous formations is an important step in their study.

The reverse position of the magnetite and hematite is difficult to understand, from both H. James' and our own observations. As a matter of fact, it is difficult to figure out, from James' text, just what segment of the iron ore cross section he did study. It is possible that a fully-developed oxide facies is tripartite rather than bipartite, in cross section, such as: shallow magnetite oxide → hematite → magnetite deep-water carbonate oxide, then carbonate. In other words, a hematite facies, within an oxide facies, is flanked on both sides by magnetite facies of various depths. If this is true, and if H. James studied the second (deeper) segment of the facies profile, the reverse position of the oxide facies in his outline is understandable. Assuming this, it is possible that our sequence of the K.M.A. ferruginous quartzites belongs to the first, the more shallow, segment of the oxide facies. If, on the other hand, this tripartite structure of the oxide facies is fictitious, the relative position of the hematite and magnetite facies, according to H. James, should be regarded as unproven.

The association of hematite-magnetite quartzites chiefly with Precambrian segments of thicker quartzites and with the present tectonic nodes (Korobkovsk, Mikhaylovsk, Saltykovsk areas) points to the origin of these rocks in deeper littoral areas with the most favorable conditions for the concentration of ferrosiliceous and other substances, both in suspension and in a colloid state (in different periods of the basin life). Apparently, these were segments of the basin bottom where the sedimentation proceeded without appreciable breaks, to achieve the maximum thickness of ferruginous rocks. It is obvious, therefore, that only these basin sectors, farther away from shore and characterized by a more consistent and unbroken sedimentary tempo, could be the deposition sites for large thicknesses of ferrosiliceous rocks in general, and especially of mixed ferrosiliceous colloids -- the source of hematite-magnetite quartzites.

In this connection, we again advance our thesis that the considerable thickness of ferruginous quartzites in present K.M.A. tectonic nodes (characterized by the development of hematite quartzites) is not the result solely of an intensive and repeated isoclinal folding of a ferruginous quartzite bed as was supposed earlier by the author and others. Most likely, the present sequence of

ferruginous quartzites was originally thicker in the sites of the present tectonic nodes because of the contemporaneous sedimentary conditions. In other words, the tectonic nodes could have been formed only in the areas of thicker sediments.

The formation of such tectonic nodes is not to be explained solely by a displacement of quartzite material from the limbs to the crests of large folds in the process of folding even though these crests do represent the nodes. There is evidence that the composition of quartzites in the crests differs considerably from that in the adjoining limbs. A mechanical squeezing alone cannot radically alter a substance, even if a tectonic compressive stress may somewhat complicate the structure of the original thick ferrosiliceous sequence. This view even better explains the nearly total lack of hematite in the areas of thin quartzites, on the limbs of large folds, and its presence in the tectonic nodes, the crests of the folds which are the original areas of thicker quartzites.

The presence of transitional poorly mineralized, commonly carbonatized and pyritized quartzites or biotite-carbonate pyritized rocks, between the middle division quartzites and the enclosing rock, and also between magnetite quartzites and metashales, within the division, is also a result of the primary facies change. It appears to be the result of a lag in the deposition of colloids and fine suspension of silica, in a facies change, after the termination of the deposition of terrigenous material or of iron hydroxides.

This is our interpretation of the patterns observed in the structure of the middle division: they have been inherited from the original sediments.

The question of these patterns being solely the result of the differences in the metamorphic effect must be unequivocally answered in the negative. Undoubtedly, a superimposed metamorphism may greatly camouflage these patterns. It is also clear, however, that the metamorphism of the original ferrosiliceous deposits has run a different course in different segments of the sequence, each with the original features of its own. The part of these original facies differences in the formation of the present middle division has been underestimated by those who look for another interpretation. It is held, for instance, that the nearly total lack of hematite in thinner segments of the middle division was because of their heating and saturation with altering solutions, with the resulting change of hematite to magnetite.

There are students of the K.M.A. who ascribe the central position of hematite quartzites between the metashales, and in the middle division as a whole, to the fact that the altering solutions easily migrate along the metashale beds and do not penetrate as far as the middle of the quartzite sequence, where hematite remains intact.

These interpretations, however, are not convincing. Obviously, in both instances, hematite-magnetite quartzites could have been preserved only in the middle part of the quartzite sequence, which was either cooler or inaccessible to altering solutions. If this were true, only one hematite-magnetite quartzite bed would have been found in the very middle of the quartzite sequence in those localities where metashales are missing (Shchigrovsk) or where there are thick quartzites between them (Oskoletsk, Saltykovo). As a matter of fact, we have seen that hematite-magnetite quartzites are, in many places, asymmetrically located in the middle division as a whole and in individual quartzite beds, where they lie close to the enclosing rocks or to the metashales. Thus, in the Yastrebovka section, a bed of muscovite-ferromicaceous-magnetite quartzite is located not in the middle of the 36 m-thick quartzite bed VII, but in its lower part, only 3.5 m from the underlying bed. The same situation has been observed in the Stoylo section and elsewhere.

In a number of localities (Shchigry, Tim, Oskolets, Saltykovo, Korobkovo), the middle division displays two and three hematite-magnetite quartzite beds, instead of one. In such cases, they alternate with purely magnetite and amphibole-magnetite quartzites.

It is also known that the permeability of metashales is not as high as that of quartzites. Consequently, metashales cannot be conductors of altering solutions. This is confirmed by the presence of poorly crystallized, i.e., slightly metamorphosed phyllites in the enclosing rocks. It follows that structural patterns in the K.M.A. Precambrian metamorphics, especially the position in them of hematite and magnetite quartzites, could not have been brought about by the metamorphic processes alone.

We submit that an intensification in metamorphism appears to have had but little effect on the alteration of primary ore minerals in quartzites. A correlation of strongly metamorphosed tremolite-magnetite quartzites of the Yastrebovka district with the very slightly metamorphosed hematite-martite and amphibole-free martite quartzites of the Tim district, fails to reveal any substantial difference in the character and the number of magnetite aggregates. These quartzites differ only in the degree of the crystallization for quartz: it is higher in Yastrebovka, and lower

in the fine-grained Tim quartzites. On the other hand, a correlation of the Tim hematite-martite (formerly hematite-magnetite) quartzites with the strongly metamorphosed Yastrebovka and Stoylo hematite-magnetite quartzites fails to reveal any difference in the relationship, form, and even the size of the hematite and magnetite. It follows that the ratios and relationships of hematite and magnetite (and of the magnetite and hematite-magnetite quartzites), which had been formed in the process of diagenesis and moderate metamorphism of structurally different ferrosiliceous deposits, persisted without substantial changes in the course of subsequent metamorphism. The only substantial change took place in the composition of the non-ore (silicate) portion of quartzites, and even that change was affected in many respects by the composition of the original deposit. We believe that the characteristic features of our primary oxide facies of ferruginous quartzites (Table 1), as well as the data on the position of these facies in the ferruginous sequence under study (Fig. 10), speak for themselves.

CONCLUSIONS

1. All the observed features of the alternation of the main types of the K.M.A. Precambrian middle division have been predetermined by the facies character of the original sediments and the conditions of their deposition. Consequently, this alternation is a stratigraphic phenomenon, and the understanding of its pattern is very important for an understanding of Precambrian stratigraphy.

2. The investigated quartzites belong to the oxide facies of the overall sedimentary iron ore cross section which also contains a magnetite (more shallow) and a hematite (deeper facies.

3. The maximum and almost exclusive development of the magnetite facies takes place east of the synclinorium axis, i.e., in rocks of its eastern limb (Stoylo, Yastrebovka). The hematite facies, on the other hand, has been developed mostly west of the synclinorium axis, i.e., on its western limb and in the southern closure (Tim, Korobkovo, Saltykovo). Thus, going from west to east and southeast, hematite facies (hematite-magnetite quartzites) change to the magnetite (magnetite quartzites) alternating with terrigenous facies (metashales). The shore line of the deposition basin lay somewhere east of the easternmost branches of the magnetic anomaly.

4. The data extant indicate that the hematite facies is best developed within certain districts of the southwestern K.M.A. belt (Gostishchevo, Yakovlev, Veretenino). This points to a general westerly deepening of the sedimentary basin.

5. The present tectonic nodes of the quartzite sequence present tectonically complicated segments of the middle division, of a greater original thickness. Inasmuch as there is method in the distribution of a considerable or predominant amount of hematite-magnetite quartzites in areas of a thick middle division, or in tectonic nodes, and of the maximum development of magnetite quartzites in thick middle division areas, there is no reason to continue the search for areas of thick magnetite quartzites alone within the known part of the K.M.A.

REFERENCES

1. Dumanskiy, A.V., DISPERSNOST' I KOLLOIDAL'NOYE SOSTOYANIYE VESHCHESTV [DISPERSION AND COLLOIDAL STATE OF SUBSTANCES]: Kiev-Kahrkov, 1932.

2. Plaksenko, N.A., OBSHCHIYE CHERTY STRUCTURY STRATIGRAFII DOKEMBRIYA KMA. ZHELEZNYYE RUDY KURSKOY MAGNITNOY ANOMALII [GENERAL STRATIGRAPHIC AND STRUCTURAL FEATURES OF THE PRECAMBRIAN IRON ORES OF THE KURSK MAGNETIC ANOMALY]: Akademiya Nauk SSSR, Izd., 1955.

3. Strakhov, N.M., ZHELEZORUDNYYE FATSII I IKH ANALOGI V ISTORII ZEMLI [IRON ORE FACIES AND THEIR ANALOGUES IN THE HISTORY OF THE EARTH]: Inst. Geol. nauk, Akademiya Nauk SSSR, Trudy, vyp, 73, geol. ser., no. 22, 1947.

4. ___________, OBSHCHAYA SKHEMA OSADKOOBRAZOVANIYA V SOVREMENNYKH MORYAKH I OZERAKH MALOY MINERALIZATSII [GENERAL SEDIMENTARY SECTION IN MODERN SEAS AND LAKES OF LOW MINERALIZATION]: Collection, Obrazovaniye osadkov v sovremennykh vodoyemakh. Akademiya Nauk SSSR, Izd., 1954.

5. James, H.G., SEDIMENTARY FACIES OF IRON-FORMATION: Econ. Geol., v. 49, no. 3, 1954.

Voronezh State University

Received October 1, 1956

DISTRIBUTION AND FORMATION CONDITIONS FOR BORON CONCENTRATION IN ENDOGENETIC BORATES OF SKARN DEPOSITS[1]

by

L. I. Shabynin

At the present time, three types of industrial deposits of boron are known: exogenetic (halogene-sedimentary), volcanic-sedimentary, and endogenetic.

The U. S. S. R. representatives of the first type are made up of assorted complex borates. The second type is unknown in the U. S. S. R., so far, although it is one of the principal industrial borates abroad. A typical instance is the Kern County, California, deposits, where boron is also found in borates, but in minerals different from those of the U. S. S. R.

The third type has a dual representation: by datolite (boron silicate) in calcareous skarn deposits, and by magnesian and ferromagnesian borates in magnesian skarn deposits.

Inasmuch as calcium borates, although known to exist, do not form commercial deposits, this paper deals chiefly with magnesian endogenetic borates.

Of the large group of magnesian borates, three occur in industrial endogenetic concentrations: ascharite (scybeliite, $2MgO \cdot B_2O_3 \cdot H_2O$), ludwigite ($(Mg, Fe^{++})_2Fe^{+++}BO_5$), and cotoite $Mg_3(BO_3)_2$. The last of the three is the most rare.

On the basis of the geologic structure and the mineral parageneses of these deposits, they are almost unanimously believed to be skarn contact metamorphic.

Magnesian and ferromagnesian borates only partially form quasi-monomineralic rocks. Usually they form parageneses with magnesian silicates and carbonates and with various ore minerals. Ludwigite, the most common primary borate of this group, commonly forms complex boron-iron ores, in association with magnetite, and with various amounts of forsterite, clinohumite, and phlogopite. The same minerals enter the silicate fraction of boron-bearing dolomitic limestones. Industrial boron concentrates in the latter are very rare (Holl-Gol, Korea), being represented only by an anhydrous magnesian borate-cotoite.

This endogenetic borate-ore characteristic usually necessitates mechanical beneficiation.

Our conclusions on the pattern of distribution and the formation conditions of this type of boron deposits have been based on the study of 67 localities throughout the world. It is to be noted that the extent of most of the foreign deposits is unknown, although their geology, principal mineral parageneses, and some other features have been adequately studied. It appears that the presence of a definite relationship between the scope and the intensity of ore-making processes may also be applied to deposits of an indeterminate and even small size. Of course, in such cases, there should be a sufficient coincidence of main geologic features, parageneses, and other aspects of these deposits with corresponding features of known commercial deposits.

A consideration of the following data is helpful as criteria for the recognition of patterns in the distribution and in the formation conditions for this type of boron deposits:

1) the geotectonic position of the deposits and of individual large concentrations of boron in endogenetic borates;

2) the relation of these concentrations with the facies composition of metasedimentary rocks containing the deposits;

3) their relation to the character of volcanism, especially to the composition of igneous rocks;

4) their relation to the age of these rocks;

[1] O zakonomernostyakh razmeshcheniya i usloviyakh obrazovaniya koncentratsiy bora v endogennykh boratakh skarnovykh mestorozhdeniy.

5) their position among the regional tectonic elements;

6) relation of the borate and other mineralizations, particularly with the elementary composition of the associated (or main) metal mineralization;

7) relationship of the borate concentrates with the prevailing regional boron shows;

8) their relation to various stages of metamorphism.

The results of the analysis of field data, according to this tabulation, are given in Table 1.

A study of this table leads to the following conclusions:

1. Most deposits are located in young folded zones, Mesozoic and Alpine, and in crystalline shields; then in the Hercynian; and least of all, in the Caledonian. The most important deposits are concentrated on the shields, but they are known also from other folded zones. Endogenetic borate deposits are unknown from the foredeep provinces and from post-Cambrian platforms. On the whole, it seems that the appearance of peripheral igneous activity, characteristic for the folded fringe of a platform, may, under favorable geologic conditions, bring about endogenetic boron mineralization.

Of course, the "statistical" data of Table 1 do not fully reflect the truly complex patterns in the distribution of endogenetic borate deposits. An analysis of the tectonic-igneous activity in the regions named might modify this picture, one way or another. As distributed, for instance, in Hercynian folded provinces, individual deposits of this type may be related also to a more ancient igneous activity.

2. Only three instances do not seem to exhibit (because of the brevity of the description) a clean-cut presence or absence of a direct relation of the borate mineralization and carbonate rocks. This relationship is evident in all other instances, with the carbonate rocks represented by dolomites or by limestones carrying forsterite, clinohumite, phlogopite, locally brucite and other magnesian minerals. The paramount importance of dolomite as a medium participating in the formation of endogenetic borate concentrations is undoubted. It is important to note, however, that dolomites from a number of platform provinces which commonly carry some boron in their gypsiferous beds, do not contain endogenetic borates.

The question of the presence of formations among the skarn dolomites with an other lithology, and specifically of some primary boron-carrying deposits, must be answered in the negative. No endogenetic borate deposits have been found outside the skarn dolomites in contact with intrusions. In the known deposits of this type, dolomites are present in rocks extremely diversified in composition and structure, of various degrees of metamorphism and of various ages, from Archaean to upper Mesozoic. A study of nonmineralized contact dolomites, in many localities, has shown the lack of chemically determinable boron. Also, there are no known parallel occurrences of exogenetic and endogenetic borate concentrates within a single deposit or district. The major exogenetic borate deposits of California are related to the Tertiary volcanism, whereas the endogenetic borate mineralization in that district is related to the Mesozoic intrusive contacts.

3. There are no known endogenetic borate deposits among the products of volcanic activity proper, i.e., in various extrusive complexes. All these deposits are associated either with direct contacts of intrusives (or migmatites) and dolomites or with narrow zones of such contacts.

Most intrusive bodies are large laccoliths and batholiths of granites, granodiorites, and quartz monzonites, commonly hypabyssal. Alkali intrusions proper, as well as basic and ultrabasic rocks, have not been found in genetic association with endogenetic borate deposits.

Within the shields, granites are represented to a considerable extent by alaskites emplaced in intensively granitized crystalline schists, carbonate rocks, and gneisses. Borate mineralization is lacking, in places of both relatively weak and very strong granitization. Specifically, an alteration of dolomites to the point where they are replaced by spinel-diopside rocks destroys the unbalanced chemical state between these and feldspathic rocks which are necessary for contact reactions. Chances for a postmagmatic borate mineralization in these zones are then determined by the intensity of the skarn-forming infiltration processes themselves and by the alkalinity of the solutions. In the granitization of dolomites to the point of their replacement by diopside-plagioclase rocks, on the other hand, there is no longer any chance, in these zones, for a postmagmatic formation of borate-carrying skarns. The magnesian medium gives place to one, unfavorable for the formation of magnesian borates.

4. The age of the granitoid intrusions is not a criterion of the borate mineralization. The known deposits are associated with

Table 1

Age of mineralization	Geotectonic region	Original enclosing rock	Age of sedimentary complex	Active igneous rocks	Age of intrusions	Presence of silicate boron mineralization	Composition of main (or associated) metal mineralization	Region	Number of localities
Precambrian	Aldan shield	Dolomites	Archaean	Alaskite granite	Archaean	Intensive	Iron, molybdenum, copper	U.S.S.R.	4
	Baltic shield		Proterozoic	Rapakiwi?	Proterozoic	Missing	Iron, zinc, lead, tungsten	U.S.S.R.	1
	Baltic shield		Precambrian	Granite	Precambrian	"	Iron	Central Sweden	6
	Indian shield		Archaean	"	Archaean	"	?	Ceylon	2
	Hercynian folded zone		Precambrian	Granitoid	Precambrian	"	?	New York State, U.S.A.	2
			"	Granitoid?	Precambrian?	"	Zinc, Iron	New Jersey, U.S.A.	2
Caledonian	Caledonian folded zone	Dolomites	Lower Paleozoic	Ademellites granodiorites	Paleozoic	Present	Iron, zinc	U.S.S.R.	4
	Caledonian folded zone		Proterozoic	Granosyenite, granite	Lower Paleozoic	Missing	Iron	U.S.S.R.	1
Hercynian	Hercynian folded zone	Dolomites	Lower Paleozoic	Granitoid	Middle Paleozoic	Missing	—	U.S.S.R.	1
			Lower and Upper Paleozoic	Granites and granodiorite	"	Present	Iron, lead, zinc	U.S.S.R.	1
			?	Granitoid	"	Missing	Tungsten, Iron	Pyrenees, France	1

Table 1 (continued)

Age of mineral-ization	Geotectonic region	Original enclosing rock	Age of sedimentary complex	Active igneous rocks	Age of intrusions	Presence of silicate boron min-eralization	Composition of main (or associated) metal mineral-ization	Region	Number of localities
Mesozoic	Mesozoic folded zones	Dolomites	Paleozoic	Granodiorite	Paleozoic (Mesozoic)	Present	Iron, copper, lead, zinc, manganese, molybdenum	U. S. S. R.	3
			"	Granite	Mesozoic	"	Iron, tin	U. S. S. R.	1
			Upper Cambrian	Quartz monzonite	Upper Mesozoic	Missing	Copper, Iron	Nevada, U. S. A.	1
	Mesozoic and Alpine folded zones		Upper Paleozoic	Quartz monzonite granodiorite	Jurassic	Present	Molybdenum, copper, iron, tin	California, U. S. A.	9
	Mesozoic folded zones	Dolomites	Devonian	Quartz monzonite	Upper Paleozoic	Intensive	Iron	Montana, U. S. A.	2
			Paleozoic	Granitoid	Mesozoic	Missing	Tin, zinc, iron	Alaska	3
			"	Granodiorite	Upper Mesozoic	"	Copper, molybdenum, zinc, lead, gold, silver, iron, tungsten	Utah, U. S. A.	6
			Upper Paleozoic	Granitoid	Mesozoic	"	?	British Columbia	1
			"	"	Cretaceous	Present	Tin	Malaya	1

Table 1 (continued)

Age of mineralization	Geotectonic region	Original enclosing rock	Age of sedimentary complex	Active igneous rocks	Age of intrusions	Presence of silicate boron mineralization	Composition of main (or associated) metal mineralization	Region	Number of localities
Mesozoic			Jurassic	Diorite	Upper Mesozoic	Missing	Iron	Bulgaria	1
	Alpine folded zone	Dolomite	Jurassic-Triassic	Granodiorites	Upper Cretaceous-Tertiary	"	Copper, Iron bismuth, molybdenum, zinc, lead	Romania	3
	Edge of Sinian shield		Proterozoic	Granite	Mesozoic	"	Gold, bismuth, copper	Korea	2
Non-differentiated	Sinian shield and adjacent folded zones		Precambrian-Paleozoic	Granitoids	Archaean-Mesozoic	?	Iron	China	6
Cenozoic	Hercynian folded zone	Dolomites	Cambrian	"	Tertiary	Missing	Iron, copper	Skye, Scotland	1
	Alpine folded zone		Silurian-Devonian	Syenite (or granodiorite)	"	"	" "	Idaho, U.S.A.	1
			Jurassic	Quartz diorite (or monzonite)	"	"	Copper, lead, zinc, iron	Yauli, Peru	1

intrusions ranging from Archaean to Tertiary.

5. On the whole, there is a relationship with the elements of the regional tectonics. Inasmuch as dolomite beds and the enclosing rocks participate in the structure of the principal tectonic elements of an ore deposit or district, the borate concentrates, being confined to the contact zones of intrusions, are associated simultaneously with more than one structure. Borate mineralization is controlled directly by disjunctive disturbances, as is generally the case in skarn and ore making. The tectonic elements, however, differ greatly in different areas, and the method of the distribution of deposits with regard to these disturbances cannot be ascertained as a general rule. It may be stated, for example, that tectonic zones in areas of bulk granitization are favorable to a more intensive granitization of the dolomite beds and to an igneous (progressive) stage of skarn formation. This precludes or at least greatly hampers the formation of the borate concentrates within these dolomitic beds, under postigneous conditions.

6. It appears that there is a relationship between the borate and other mineralizations, under any conditions. In all known deposits, borates are not present as such but always in direct or indirect associations with other mineralizations.

Major endogenetic boron concentrations are only indirectly, if at all, related to the elementary composition of metal mineralization. Such concentrations are known from iron skarn deposits (U. S. S. R., China, Romania, Bulgaria, U. S. A., Sweden), tin deposits (Alaska, U. S. A.), copper, bold, and bismuth (China), copper and lead, molybdenum and bismuth (Romania), copper (U. S. A.), iron and tungsten (U. S. S. R., France) in association with other minerals.

The relationship between the mineral composition of borates and that of metal mineralization is not, as yet, adequately known. It only can be stated that ludwigite is the principal borate of iron ore deposits, and that the appearance of cotoite concentrates (cotoite + magnetite = ludwigite) is impossible in zones of magnetic mineralization of such deposits.

7. The commonly observed direct relationship between the size of borate concentrations and that of the associated (or main) mineralization is obviously not universal.

The presence of endogenetic boron, other than in borates, does not imply the presence of borate concentrates in the skarn deposits of other useful minerals of the region. Out of 67 known endogenetic borate deposits, only 7 (including 2 major ones) exhibit boron shows as tourmaline and axinite in feldspathic rocks. In addition, tourmaline and axinite are widely developed in a number of diversified rocks, in relation to igneous and hydrothermal processes, in which cases borate mineralization is lacking in the corresponding petrographic complexes and mineralization zones.

As an example, there is a boron-bearing province identified by Academician S. S. Smirnov in the northeastern Soviet Union. This province, comprising the region east of Lake Baikal, is a segment of a wider Pacific ore belt which is characterized by the abundant presence of boron. No endogenetic borate concentrations have been as yet found in individual parts of this northeastern province, despite the abundance of boron in silicates. In other parts of it, the borate mineralization is not accompanied by any large development of boron silicates. Finally, some of the localities are marked by an intensive mineralization of both kinds. Correspondingly, borate mineralization is intensive and diversified along the west coast of North America, from Alaska southward. Even there, the association of borate and an essentially aluminum silicate mineralization in magnesian skarns is rare.

Individual areas of a boron-bearing province may lack borate-type boron concentrates; conversely, considerable concentrates of that type may be found in areas of low-silicate boron.

8. The fact that magnesian skarns are formed at both the postmagmatic (regressive) and magmatic (progressive) stages of metamorphism makes it necessary to specify the position of endogenetic borates participating in the parageneses, along with other skarn and ore minerals.

Features of the geologic structure and of the parageneses of deposits in crystallines of ancient shields have led to an unanimous agreement on a postigneous stage for the formation of endogenetic borates in magnesian skarns of these deposits. Less clear is the position of borate mineralization in the hypabyssal skarn-ore deposits, where postigneous processes (including the development of calcareous skarns) have been superimposed on the magmatic stage magnesian skarns. This phenomenon has not been sufficiently studied; however, the possibility of the formation of cotoite in the Hol-Goll limestones, as well as of certain ludwigite skarns at an igneous stage cannot be ruled out.

A preliminary study of the formation conditions for magnesian and ferro-magnesian

borates in skarn deposits leads to the following conclusions:

Borates are concentrated usually in outer zones of a metasomatic column, made up of a forsterite (clinohumite) or a phlogopite skarn. Considerable concentrations of such borates in dolomitic limestones and in diopside skarns are rare.

Parageneses of ludwigite in association with diopside are possible only at high concentrations of boron in solution, and their distribution is very small.

The igneous stage skarns, in deposits related to crystalline complexes of the Aldan deep facies, are represented by spinel-olivine, hypersthene, and spinel-diopside rocks. Syngenetic borate mineralization is unknown in them; in those places, however, where they have been altered to phlogopite skarns under postigneous conditions, ludwigite may be developed along with the phlogopite. It is possible, on the other hand, that under the hypabyssal conditions too, borates are deposited at a postigneous stage, along with the postskarn mineralization.

All these data point to the necessity of the identification of those varieties among the dolomite-granitoid contact skarns whose mineral parageneses are favorable to the development of borates. It has been accepted as a fact that of all the infiltration skarns, only the dolomite-replacing exoskarns can be borate bearing. Skarns which have been developed on aluminum silicate rocks are not borate prospects. Such skarns are usually made up of clipopyroxenes with ferruginosity $fm > 20 \left(fm = \frac{\Sigma\, Fe_{mol}}{\Sigma\, Fe_{mol} + Mg_{mol}} \times 100 \right)$, hornblendes, and essentially ferruginous phlogopites ($f_m > 10$, $\gamma > 1.590$), whereas the similar exoskarns are characterized by the ferruginosity of phlogopite of as much as 10%, and that of clinopyroxene as much as 20%. Hornblende skarns of dolomites are unknown. Nor are there any known instances of borate mineralization in hypersthene skarns (igneous stage).

In view of the above, it should be stated that the special conditions determining the origin of endogenetic borate deposits are not clear, at the present time. Even the very existence of such conditions is not quite clear, other than the presence of adequate concentrations of boron in postigneous solutions. In any event, this problem is related to the causes determining the presence of mineralization in some granitoid intrusion contacts and its absence in others, with the same character of the enclosing rocks. With respect to endogenetic borates the situation is as follows.

All known industrial phlogopite deposits of the world occur under similar geologic conditions. Despite the fact that these conditions completely duplicate those of the boron-ferruginous ore deposits (ludwigite-magnetite), on shields, no instances of borate mineralization in the phlogopite deposit skarns have been found.

The following observations are pertinent with regard to prospecting for endogenetic deposits.

1. Both the endogenetic borates and datolites, in large concentrations, are known in association with skarn-ore processes, from contacts of granitoids and carbonate rocks. Despite the comparatively smaller distribution of the dolomitic facies of these rocks in geosynclinal provinces, as compared with the dolomitic facies, the commercial concentrates of datolite appear to be less common than those of endogenetic borates.

2. The established similarity in the geologic position of both types of boron concentration permits a general geologic evaluation of the commercial boron prospects in areas of poorly known facies composition of carbonate rocks.

3. No single criterion should be used in the evaluation of the prospects of a region or a deposit. Rather, a combination of all possible criteria for the method of the formation and distribution of the boron concentrates in the skarn deposits must be applied to the task.

It should be emphasized, in conclusion, that halogene-sedimentary, volcanic sedimentary, and datolite concentrations are the most interesting among the industrial sources of borates. However, the first type of deposit is very rare, and the second is unknown in the U. S. S. R., for the time being. A geologic study is, therefore, essential, for the purpose of finding volcanic-sedimentary boron deposits in the U. S. S. R. In the meantime, a considerably better development of endogenetic boron concentrations in skarn deposits, as compared with that in datolite, has been indicated by recent study. For this reason, a broadening of the search for boron, to include the endogenetic borates along with the halogene-sedimentary and datolite, iis to be seriously considered.

The designation of regions favorable for the search for skarn deposits of boron, in both borates and datolites, calls for a facies study of carbonate deposits in the contemplated areas. Unfortunately, our knowledge along these lines is very small, even in comparatively more familiar regions. The chemical composition of carbonate rocks has

been very little studied, even in ore regions. As a rule, lumped together as limestones, are even those carbonate rocks which, in skarning, are characterized by parageneses suggesting an unquestionably dolomitic nature of the source carbonates. Such a state of affairs cannot be viewed with equanimity, and more attention should be given to the study of the facies composition of carbonate rocks in folded provinces.

REFERENCES

1. Kurman, I. M., GEOLOGICHESKIYE ISSLEDOVANIYA MESTOROZHDENIY BORSODERZHASHCHIKH POROD NA GORAKH BYK I ZOLOTOY KURGAN [GEOLOGIC STUDY OF BORON-BEARING ROCKS IN THE BYK AND ZOLOTOY KURGAN MOUNTAINS]: Nauch.-issled. Inst. po udobreniyam, Trudy, vyp. 125, 1934.

2. Kurman, I. M. and Z. M. Usacheva, GEOLOGICHESKOYE STROYENIYE I GENEZIS DATOLITOVYKH MESTOROZHDENIY MINERALOVODSKIKH LAKKOLITOV [GEOLOGIC STRUCTURE AND ORIGIN OF THE DATOLITE DEPOSITS IN THE MINERALOVODSK LACCOLITHS]: Ibid, vyp. 142, 1937.

3. Marakushev, A. A., SVYAZANNYY S GRANITIZATSIYEY METASOMATIZM DOLOMITOVYKH MRAMOROV I KRISTALLOSLANTSEV NA TAYEZHNOM ZHELEZORUDNOM MESTOROZHDENII V ARKHEYE ALDANSKOY PLITY [GRANITIZING METASOMATISM OF DOLOMITIC MARBLES AND CRYSTALLINE SCHISTS IN THE TAYEZHNYY IRON ORE DEPOSIT OF THE ALDAN SHIELD ARCHAEAN]: Dal'nevost. filial Akademiya Nauk USSR, Trudy, ser. geol., t. 3, 1958.

4. __________, PARAGENIZISY BORSODERZHASHCHIKH SKARNOV V TAYEZHNOM MESTOROZHDENII V ARKHEYE ALDANSKOY PLITY [PARAGENESES OF BORON-CARRYING SKARNS IN THE ALDAN SHIELD ARCHAEAN]: Geokimiya, no. 1, 1958.

5. Mel'nitskiy, V. V. and I. M. Kurman, O NOVOM MESTOROZHDENII BORSODERZHASHCHIKH DATOLITOVYKH POROD [A NEW BORON-CARRYING DATOLITE ROCK DEPOSIT]: Tekh. inform. Gos. Inst. gorno-khim. syr'ya, no. 2, 1947.

6. Shabynin, L. I., O GENEZISE YUZHNO-YAKUTSKIKH ZHELEZORUDNYKH MESTOROZHDENIY [THE ORIGIN OF THE SOUTH-YAKUTSK IRON ORE DEPOSITS]: Akademiya Nauk USSR, Izv., ser. geol., no. 1, 1958.

7. Geijer, P., THE PARAGENESIS OF LUDWIGIT IN SWEDISH IRON ORES: Geol. Fören. Förh., vol. 61, no. 2, 1939.

8. Watanabe, T., GEOLOGY AND MINERALIZATION OF THE SUAN DISTRICT, TYOSEN (KOREA): Journ. Fac. Sci. Hokkaido Univ., no. 3-4, 1943.

Institute of the Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry; the Academy of Sciences, U. S. S. R.
Moscow

Received December 16, 1957

AGE OF THE NORTHWEST CAUCASIAN PYRITE MINERALIZATION[1]

by

A. V. Netreba

The origin of pyrite deposits has been the subject of many papers, with various authors treating this topic in essentially different ways as regards the prospecting criteria for these ores.

The problem of the origin of pyrite deposits has been studied chiefly on information provided by the long-exploited mines of the Urals, Altai, and Transcaucasus. Two schools of thought have emerged, known as the "intrusive" and "extrusive." The adherents of the first [5, 7, 9, 16, 19, 24] believe that the pyrite mineralization is genetically connected with deep-seated magmatic hearths of granitoid intrusions. According to them, pyrite deposits have been formed through a metasomatic replacement of appropriate rocks by hydrothermal solutions, with pyrites concentrating in fault zones, cleavage planes, or readily replaceable beds. Thus, the Ural and Altai ore bodies have been formed in already regionally metamorphosed volcanic-sedimentary sequences, and the differences in their composition and structure are explained by the primary features of ore making.

A.N. Zavaritskiy [7, 8] and his followers [2, 17, 11, 12, 22, 23] advance a hypothesis differing in principle from the intrusive concept. Accordingly, pyrite deposits are related to volcanic-sedimentary sequences not only spatially but genetically as well, specifically to the roots of the volcanic sources of those extrusives among which they are found. The ores were deposited as a result of the activity of solfataras and fumaroles, having metasomatically replaced the contemporaneous formations under the conditions of near-surface ore making, at low pressure and moderate temperatures as a single stage mineralization, i.e., a single ore-making phase. The subsequent intensive dynamic regional metamorphism altered the enclosing rocks to green schists and changed the form and mineral composition of the ore bodies. The differential regional metamorphism was responsible for the difference in structure and composition of the ore bodies.

The effect of the regional metamorphism is supposed to be the decisive factor in the study of pyrite deposits. It stands to reason that if an ore is affected by regional metamorphism, it must have been contemporaneous with the volcanic sedimentary sequence. If, on the other hand, pyrite ores are not affected by the metamorphism which strongly altered the enclosing rocks, there is no need to relate them to the magmatic hearths of the volcanics.

There are some deviations from the two extreme views. Thus, P. F. Ivankin [9, p. 75] believes that "intrusions of various ages, the later extrusions, with lavas and tuffs emplacing them, on one hand, and the polymetal sulfide ore deposits, on the other, are related not as a product to its source but as diversified products to a common deep-seated source."

Ye. K. Lazarenko [5], in his study of the age relationship of schists and ore bodies, arrived at the concept of a multistage origin of pyrite ores. These ores are considered to be sedimentary bodies which were subjected to regional metamorphism, together with the contemporaneous tuffaceous sequence. Copper-zinc mineralization was superimposed on the pyrite bodies by hydrothermal processes which affected the Hercynian granitoids after the metamorphism.

Thus, there is no unity in the opinions on the origin of the pyrite-ore deposits and on reliable prospecting criteria, even for the well-known ore provinces of the Urals, Altai and Trans-Caucasus. Accordingly, a study of this problem in a new ore region such as the north Caucasus is of outstanding interest. The assimilation of pyrite deposits there, has not gone beyond the reconnaissance of a few comparatively recently discovered deposits. The only publication on the

---

[1]O vozraste kolchedannogo obrudeneniya na severo-zapadnom kavkaze.

Caucasian pyrites is a paper by N. V. Ivanov [11] who studied the Urup deposit.

There are two ways to determine the relative ages of ore bodies and of regional metamorphism. One, structural, was used by A. V. Pek [7, 9] in a well-known work on the Levikhinsk and Degtyarsk deposits, based on a study of a large number of mines. This method is unsuitable in the Caucasus where the exploration is done chiefly by core drilling.

The second way, that of a microscopic study of ores and the enclosing rocks, combined with the geology, was used by such students of the Uralian, Altai, and Trans-Caucasian pyrites as T. N. Shadlun [7, 22, 23], D. P. Grigor'yev [5], Ye. K. Lazarenko [15], P. F. Ivankin [10], S. A. Vakhromeyev [4], I. G. Magak'yan [16], and others.

This was the method used by the author on the material from the northwestern Caucasian pyrite deposit, chiefly from the Beskes mining district, in determining their age, relative to the regional metamorphism.

THE OCCURRENCE OF THE PYRITE ORE BODIES

In the north Caucasus, the pyrite deposits are located in the Front Range tectonic zone where they are associated with middle Paleozoic schists.

The sedimentary-volcanic sequence opened with thick terrigenous, fine clastics, subsequently altered to phyllites. Fractures in the crystalline basement vented first basic then acid magmas. These flows alternated with tuffaceous sediments, to form, according to A. V. Peyve [17, 18], a volcanic-sedimentary sequence very typical of geosynclinal conditions. The acid magmas, especially plentiful toward the end of the igneous stage, did not always reach the surface; most of them solidified under hypabyssal conditions, forming conformable interbedded deposits: sills and cutting dikes of an albitophyre composition (roots of the volcanic centers). The following period of igneous quiescence is reflected by the deposition of limestones and of the upper quartzite and slate formation. Differential block movements along fault planes brought about an uplift of intrusive bodies, folding, and the development of disjunctive movements at the upper structural stages, all processes inseparable from each other.

The intrusive cycle opened with ultrabasic intrusions, went through intermediate stages (diorites), and terminated in plutonic granodiorites of the Beskes-Moshchevoy type. The granodiorite intrusion was accompanied by the development of hypabyssal dikes, lamprophyres, aplites, and vein granites. Toward the close of the tectonic-igneous cycle, hydrothermal solutions separated from the magmatic hearth, formed a series of vein ore bodies of a diversified mineral composition at the upper structural stages.

The intrusions and the intensive folding pressure regionally and strongly altered the volcanic-sedimentary sequence to phyllites, green schists, schistose albitophyres, porphyroids, and porphyritic rocks. The petrography of this sequence is described in papers of N. A. Ignat'yev [13], I. Ya. Baranov [1], and Yu. D. Bochkovoy [3].

The metamorphic schists developed banded, granoblastic and lepidoblastic textures and thin partings, all typical features of rocks which were subjected to an intensive directed pressure. The mineral composition was fully altered to secondary minerals: albite, chlorite, epidote, quartz, carbonates, actinolite, with rare isolated relicts of the primary textures and minerals. Such a complete alteration on a regional scale is the result chiefly of the thorough heating of the sequence by the large granitoid intrusions [21]. A material composition grading indicates that the metamorphic process was greatly affected by exchange reactions in the circulation of pore-filling solutions. Thus the regional change of the volcanic-sedimentary sequence to green schists was not determined by the dynamics of folding, alone. A decisive part was played by pre-upper Carboniferous plutonic granodiorite intrusions. A fringe of contact crystalline schists, made up of higher-temperature minerals, was formed about the granodiorite massifs [20]. Everything considered, it is more proper to speak of a regional low-temperature contact metamorphism rather than of a regional dynamic metamorphism.

Pyrite deposits usually trend parallel to the schistosity of the enclosing rocks. They are usually veinlike, less commonly lenslike, associated with the limbs of transversal domal uplifts which usually complicate the anticlinal structure of the Front Range. Their position is closely related to the contact planes of rocks having sharply different composition and physical properties.

Hydrothermal alterations, sericitization, quartzitization, carbonatization, etc., appear in narrow bands fringing the ore bodies with schistose albitophyres altered more intensively and over longer distances, regardless of whether they are located at the top or at the base of the ore body. They have, commonly been altered to quartz-albite-sericite and quartz-sericite schists.

TYPES OF PYRITE ORES

The ores of pyrite deposits are of two distinct groups, disseminated and massive. Some disseminated ores contain irregular segments of massive ore (the Gorelaya ravine), whereas some massive ore bodies contain breaks along both the strike and dip, the "misses" of the Uralian geologists (Beskesskoye, Chernorechenskoye). In most instances, however, the two groups occur separately.

1. Disseminated ores are schistose sericitized albitophyres, broken by thin fractures filled with quartz. The bulk of sulfides -- pyrite and chalcopyrite -- is concentrated in the quartz veins, with only a fraction replacing the silicates in the enclosing albitophyres. The ore grade fluctuates in a wide range (K = 5 to 30). Iron and copper pyrite ores are distinguished according to their mineral composition. The first are represented exclusively by pyrite. Its euhedral grains, 2 to 4 mm long, show practically no evidence of cataclastic stresses.

Copper pyrite disseminated ores consist of euhedral chalcopyrite grains, 1 to 4 mm, some of them fractured and split. Iron pyrites predominate over the copper, with the latter developed in fractures of the former or in the junction of its grains, in bodies with corroded outlines. The disseminated copper pyrite ores contain irregular accumulations of sulfides, 1 to 4 mm, approaching the massive ores in their composition and texture. Spectrum analyses suggest the presence of gold. However, no gold has been found in polished sections. The gold appears to be finely dispersed in sulfides.

2. Massive sulfide ores are of three types, according to their textural and structural features, mineral composition and, consequently, their industrial value. Despite their sharp differences, they form a number of transitions.

a) Iron pyrite massive ores have visible quartz inclusions. The ore texture is subhedral-granular or else porphyritic because of the phenocrysts of quartz or pyrite crystals (Fig. 1). The groundmass is fairly evenly granular, with 65 to 75% euhedral pyrite grains, 0.5 to 2.0 mm, and with hardly any evidence of cataclastic stresses. The vein minerals, quartz, sericite, and chlorite, account for as much as 30% of the section area. Locally, the pyrite grains are fractured and shattered, with chalcopyrite and less commonly sphalerite appearing among them. The grains are not larger than 0.1 to 0.5 mm, and the area of their distribution is not more than 2% of the entire polished section. The color of the ore is gray-yellow.

FIGURE 1. Iron pyrite ore.

Polished section 19/6; magnification, x 64.

There are isolated unaltered large "floating" blocks and fragments of the enclosing rocks, albitophyres and albite-chlorite schists. The fragments are distinctly schistose. In some, the schistosity orientation is different from that in the enclosing rock. Ores of this type make up the peripheral bulk of the deposits; in the central part they occur sometimes only in the hanging block.

b) Copper pyrites are massive with fine grained, granoblastic, less commonly brecciated texture, straw-yellow to bronze- or brass-yellow. These ores are 80 to 90% pyrite, with grains not more than 0.1 to 0.5 mm. Vein minerals are fairly well developed (as much as 18% of the polished section area) among the pyrite grain aggregates. As a rule, the pyrite grains are fractured, cataclastic, split, with the individual parts displaced relative to each other. The fractures in the pyrite aggregates are associated with chalcopyrite separates, in many cases forming corroded boundaries with the surrounding pyrite. Sphalerite is less common. The isolation of copper and zinc sulfides in individual fractures is characteristic, with both sulfides corroding pyrite and less commonly, quartz. Quantitatively, chalcopyrite (as much as 5%) predominates over sphalerite (seldom more than 1%). There are a few bornite grains and isolated fine grains of gold, in all cases associated with chalcopyrite.

c) Banded copper-zinc ores are the richest in copper and zinc. They usually make up the lower side of the ore body and occur in the thickest swellings of a deposit. Macroscopically, they are recognized by the appearance of steel-gray bands, 2 to 10 mm wide on the general brass-yellow background. These bands are commonly parallel to the selvage; at times they form an intricate pattern of crisscross fractures by branching off, bending, swelling, and wedging out (Figs. 2, 3, 4).

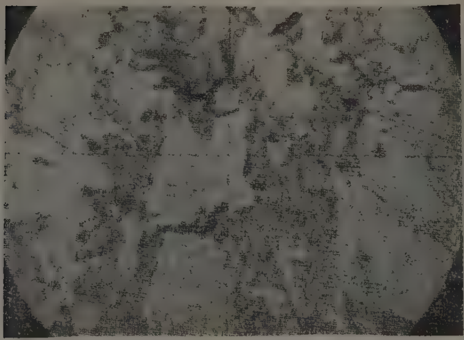


FIGURE 2. Banded ores. Sphalerite and chalcopyrite corroding pyrite.

Polished section 2322; magnification, x 640.

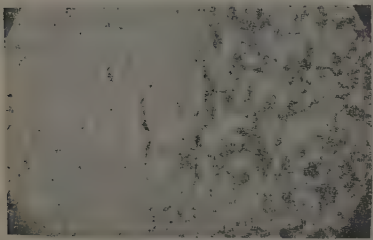


FIGURE 3. Banded ores. Boundary of a sphalerite-pyrite and a pyrite-chalcopyrite band.

Polished section 767; magnification, x 140.

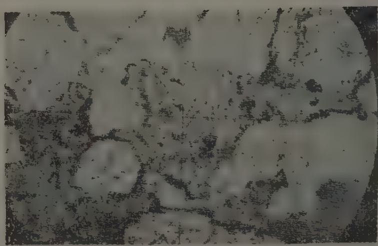


FIGURE 4. Twin bands in processed (with a mordant) sphalerite.

Polished section 2328; magnification, x 640.

Table 1

Ore type	Zinc-copper	Copper	Pyrite
Ore color	Bronze-yellow with gray bands	Bronze to brass-yellow	Gray-yellow
Structures	Banded	Massive	Massive with visible quartz inclusions
Textures	Crumbled Glomeroblastic	Glomeroblastic	Porphyritic subhedral
Grain size, in mm	0.01–0.2	0.1–0.5	0.5–2.0
% content			
FeS_2	70–80	80–90	65–75
$CuFeS_2$	3 and more	1–4	less than one
ZnS	4 and more	one and more	less than one
Vein	5–12	12–18	25–35
Volumetric weight	4.4–4.7	4.0–3.0	3.7–3.9

The boundaries between the brass-yellow and steel-gray bands are mostly sharp. The latter display a crumbled structure. The shattered, commonly crumbled, fractured pyrite grains, 0.02 to 0.1 mm, barely touch each other, being immersed in an aggregate of euhedral sphalerite grains which corrode the pyrite grains, commonly completely replacing them. There are very few galena grains. For vein minerals, there is quartz with rare barite and calcite.

The bronze-yellow bands consist chiefly of comparatively less shattered pyrite grains with anhedral chalcopyrite separates. The chalcopyrite grains fill the space between the pyrite grains, and penetrate their aggregates through the fractures, partially replacing the pyrite.

THE PHASES OF ORE MAKING

The relationship of minerals in ores, the different degree of shattering, and finally the spatial relationship of mineral associations in different ore bodies, make it possible to establish several phases of ore formation.

1. The pyrite phase of mineralization is characterized by the quartz-pyrite paragenetic association and is the most common. In all, all pyrite ore bodies were formed in a pyrite mineralization phase. Most ore bodies, namely the most common disseminated pyrite ores, have been made up only of pyrite and quartz. For one reason or another, other mineralization phases have not been active in these ores. In massive ores, this phase is represented by pyrite alone.

Ye. K. Lazarenko [5] regards the formation of these ores as sedimentary, syngenetic with the deposition of the tuffaceous sequence. Although the accumulations of sedimentary pyrite are not uncommon, and although such ores have been subjected to the maximum pressure, this mode of origin can hardly be associated with the Beskes ores. The pyrite ores carry fragments with a previously formed schistosity. Now, a metamorphism of these fragments, contemporaneous with that of the enclosing rocks, should have produced a commonly oriented schistosity. It so happens that the schistosity of fragments does not coincide, in many instances, with that of the rock, thus suggesting a displacement of already metamorphosed fragments in the process of ore-making.

2. The copper pyrite mineralization phase is more localized than the presious one. The paragenetic association -- quartz, chalcopyrite, and pyrite -- has not been superimposed, by any means, on all pyrite ores. In disseminated ores, it is known from the Gorelaya and Grushevaya ravines. It forms the Beskes massive copper ores. Pyrite grains are strongly cataclastic in those local-

Table 2

Minerals	Enclosing rocks	Hydrothermal process (phases)			
		iron pyrite	copper pyrite	poly-metal	galena-barite
Albite	+++	–	–	–	–
Chlorite	+++	++	–	–	–
Quartz	+++	+++	+++	+++	+++
Sericite	+++	+++	++	+	–
Actinolite	+++	–	–	–	–
Epidote	+++	–	–	–	–
Calcite	+++	–	–	+	++
Sphene	+	–	–	–	–
Zircon	++	–	–	–	–
Pyrite	–	+++	++	–	–
Marcasite	–	+	–	–	–
Chalcopyrite	–	–	+++	+	–
Bornite	–	–	++	–	–
Gold	–	+?	++	–	–
Sphalerite	–	–	–	+++	–
Galena	–	–	–	+	++
Barite	–	–	–	+	+++
Gypsum	–	–	–	–	++
Kaolinite	–	–	–	+	++

+++ much; ++ average; + little; – absent; ? doubtful.

ites where the copper pyrite mineralization phase has been operative. The copper-bearing solutions followed the system of fractures in the aggregate of previously deposited minerals. In isolated instances, this phase was not superimposed on the pyrite ores but rather formed independent ore bodies, small quartz lentils with abundant separates of chalcopyrite and scarce pyrite associations, such as in the hanging wall of the Beskes pyrite deposit. Even more scarce are the conformable quartz veins with chalcopyrite in green schists (the Beskes and Khatsavitaya Valleys).

3. The polymetal mineralization phase. The paragenetic association, sphalerite, quartz, barite, calcite, and galena, is fully developed only in those massive sulfide ores which underwent a considerable subsequent shattering. As a result of the superposition of a new mineralization phase, whose solutions circulated through the network of fractures, banded ores were formed as a result of the telescoping of several mineralization phases.

4. The latest and most localized galena-barite paragenetic association is present only in the upper beds of small quartz-barite veins with galena, calcite, and gypsum accompanying the pyrite bodies (the Khatsavitaya Mountain, Krasnaya Ravine). Table 2 lists the paragenetic mineral associations according to the phases of the hydrothermal process.

N. V. Ivanov [11] counts as many as 5 phases for the Urup pyrite bodies; I. G. Magak'yan counts 8 phases for the Trans-Caucasian pyrite bodies, although not all of them are present in one place.

Each mineralization phase is characterized by a paragenetic association of its own and by a geochemical complex of added elements. It is also divided according to the periods of time between the tectonic impulses which squeezed out new batches of ore-carrying solutions into newly opened migration paths. The same tectonic pushes brought about the shattering of the enclosing rocks and of previously formed ore minerals in segments housing the ore bodies, in the structural-lithologic "traps". The influx of new ore-carrying solutions, substantially different in their composition, resulted in a metasomatic replacement of fragments of the enclosing rocks and of previously formed ore minerals. The ore-making process grew less intensive with each succeeding flux of the solutions.

GEOCHEMICAL FEATURES OF THE ORE MAKING

The distribution of elements according to the mineralization phases is presented in Table 3, compiled from the data of a mineralogic study and of chemical and spectrum analyses.

Table 3

Elements	Enclosing rocks	Hydrothermal process (phases)			
		iron pyrites	copper pyrites	poly-metal	galena-barite
Aluminum	+++	–	–	–	–
Barium	–	–	–	+	+++
Gallium	–	–	–	+?	–
Germanium	–	–	–	+	–
Iron	++	+++	+++	+	–
Gold	–	+?	++	–	–
Indium	–	–	–	+?	
Cadmium	–	–	–	+	–
Potassium	+++	+++	++	+	–
Calcium	+++	–	–	+	+++
Oxygen	+++	++	++	++	+++
Silicon	+++	+++	+++	++	+++
Magnesium	+++	–	–	–	–
Manganese	+	–	–	–	–
Copper	–	–	+++	+?	–
Molybdenum	–	+?	–	–	–
Arsenic	–	+?	–	–	–
Sodium	+++	–	–	–	–
Lead	–	–	–	+	++
Sulfur	+?	+++	+++	+++	++
Silver	–	–	?	+	+
Titanium	+	–	–	–	–
Zinc	–	–	–	+++	–
Zircon	+	–	–	–	–
Chromium	+	–	–	–	

+++ much; ++ average; + little; – absent; ? doubtful.

Molybdenum has been found in a few grains in polished sections from the upper Red Ravine quartz veins in disseminated ores. Arsenic in pyrite was determined by microchemical reactions, but has not been confirmed by spectrum analyses. Gallium and indium were detected as faint lines in a few sphalerite spectra. Cadmium and germanium were present, from 0.001 to 0.01 percent, in all sphalerite spectra.

Practically lacking were elements common in basic rocks: platinum, chromium, nickel, cobalt, and others; as well, incidentally, as those common for the acid series: tungsten, molybdenum, and tin. Most probably, the geochemical complex is more typical of those ore-carrying solutions which split from the magmatic hearth, at a granodiorite magma formation stage.

THE AGE OF ORES AND THEIR RELATION WITH METAMORPHISM

T.N. Shadlun [7, 22] points out that differences in the mineral composition, structure, and texture of pyrite ores are in direct relation to the degree of metamorphism of the enclosing rocks. The south Urals ores, emplaced in volcanic-sedimentary rocks slightly altered by regional metamorphism, are marked by colloform structures and textures, with marcasite, melnikovite, and wurtzite present in large amounts. In the middle Urals, the sulfides of iron and zinc are represented by pyrite and sphalerite, and the colloform structures disappear. The Japanese "kuromono" ores are believed to be the nonaltered correlatives of the banded ores; this usually without taking into consideration that a primary differentiation has been observed in the Japanese ores, as well. The correlatives of our copper pyrite and copper ores are the "oku" and "keiko" ore types [14, 25].

At the present time, ores are known from the Caucasus, which are emplaced in rocks with a comparable degree of metamorphism. They are definitely correlative with Uralian deposits.

Two deposits, the Beskes and Urup, do not clearly display the relationship established by T.N. Shadlun [7, 22]. The principal ore mineral there is pyrite, crystallizing mostly in hexahedrons, at times in pentadodecahedrons (Urup). Marcasite and melnikovite are present to a very small extent. Wurtzite has not been found. Concentric zonal structures have been observed, in few places, in the Urup ores, and not at all in the Beskes ores. It should be noted that P.F. Ivankin and N.M. Mitryayeva [10] have shown on the Nikolayevsk ores that colloform textures and structures are not relicts of a primary premetamorphic ore deposition, but rather are characteristic of a later mineralization phase.

The halo of disseminated ores, which accompanies the massive ore bodies, consists exclusively of pyrite. The "least mobile" pyrite of the crystalloblastic series [T.N. Shadlun, 7] is disseminated on both sides of the ore body and is readily extended toward the hanging block. The somewhat more mobile sphalerite, forms stable and large concentrates in the lower side of the ore body. The most "mobile" chalcopyrite has several maxima (usually two) of its content in different sections of the ore bodies. Such relationships cannot be explained by the migration of ore minerals as an effect of directed pressure.

Two types of banding occur in the Beskes ores. The intricate Uralian banding pattern of Ye. K. Lazarenko [15] is a result of the replacement of pyrite by sphalerite throughout the network of fractures formed in the shattering of the ore aggregate. The regular banding is more difficult to explain. The S.A. Vakhromeyev [4] application of structural analysis to specimens of the Third International pyrite ores is of great interest.

Some authors [7, 8, 22] associate the formation of regular banding with the recrystallization and migration of chalcopyrite and sphalerite as an effect of directional pressure in regional metamorphism. The origin of banding in pyrite ores, as a result of metamorphism, is believed to be an important proof of the simultaneous formation of pyrite deposits and the extrusive-sedimentary sequence.

Twins on (111) are known to originate in mechanically deformed sphalerite [6]. S.A. Vakhromeyev states [4, page 150], "just as the twin sutures in calcite, in mechanical deformation, are oriented parallel to the cleavage planes, the twinning in sphalerite is also oriented. The position of striations in sphalerite will then determine the spacial orientation of the ore-aggregate grains."

A similar change in the optical orientation of quartz, albite, mica, and other mineral grains in metamorphic rocks has long been known. For this reason, S.A. Vakhromeyev's view of the sphalerite twinning sutures controlling the spatial orientation of minerals, and consequently the direction of the tectonic pressure responsible for the mechanical deformations in ores, merits a great deal of attention.

The following method was used in the study of the Beskes specimens of banded ores.

The polished section was processed for 2 to 3 seconds in aqua regia vapor, to bring out the twin structure of sphalerite grains, then placed on the coordinate carriage of the microscope table. As many as 200 measurements of the angles between the direction of banding and that of the sphalerite twinning sutures were made in each polished section. From these data, tectonic rose diagrams were constructed for the direction of the twinning sutures, where vertical lines corresponded to the direction of the banding.

The comparison of the mineral orientation in the ore body was made on polished sections of narrow-banded albite-chlorite schists from the hanging wall of the ore deposits. Both the basic mineral composition and the banded structure in these rocks are clearly, of a metamorphic origin. The band effect is due to the alternation of secondary minerals, albite and chlorite. A correlation of the mineral grain orientation in green schists -- the products of regional metamorphism -- with that of the sphalerite grains from the ore deposits is supposed to reveal the relation of the latter to the regional metamorphism (Figs. 5, 6, 7).

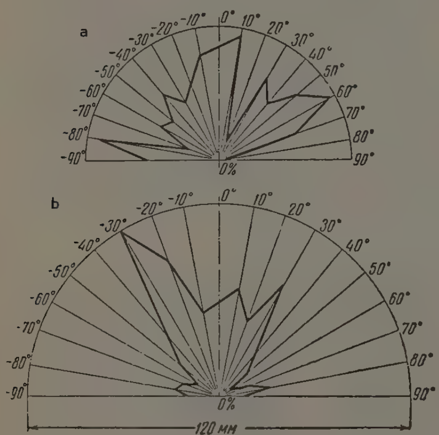


FIGURE 5. Definite orientation of twinning sutures in sphalerite is lacking (a, polished section 419); diagonal orientation of such sutures (b, polished section 2326).

200 measurements of sphalerite grains.

Obviously, if an ore body was contemporaneous with the enclosing rocks, a coincidence in the banding orientation in both and in the orientation of the mineral grains is to be expected. The banding in both rocks

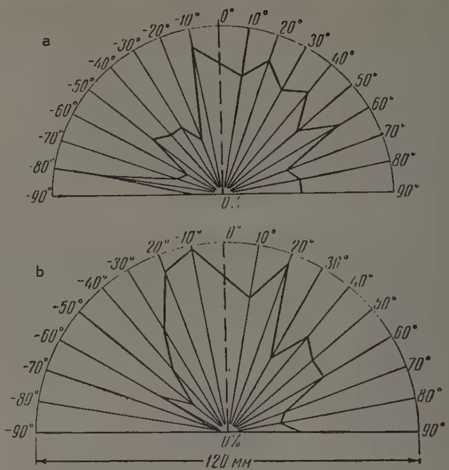


FIGURE 6. Definite orientation of twinning sutures in sphalerite is lacking (a, polished section 412. 173 measurements of sphalerite grains); straight orientation of such sutures (b, polished section 2328; 230 measurements of sphalerite grains).

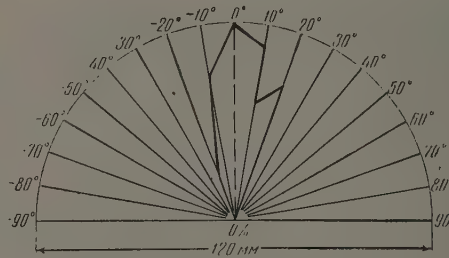


FIGURE 7. Straight orientation of α^1 axes of the albite grains (polished section 142; 211 measurement of the albite grains).

and ores is a result of the recrystallization and migration of silicates and sulfides, under pressure.

If the ore body was formed after the main phase of the regional metamorphism of the enclosing rocks, a divergence in the orientation of ore grains and that of the banding is to be expected, since the latter no longer reflects the metamorphic effect but rather the conditions of the primary ore making.

Finally, in the absence of a regular orientation of sphalerite grains in the ore and of minerals in albite-chlorite schists, as compared with the direction of the banding, this

method of the structure analysis is not a criterion for the role of regional metamorphism in the formation of pyrite ores.

The angle measured in polished sections of albite-chlorite schists was that between the direction of the banding and the orientation of axis α^1 of nontwinned albite grains.

The results are presented in a tectonic rose diagram; a more precise method would be meaningless because of the impossibility of contructing a similar diagram for the sphalerite grains.

Altogether, 9 specimens of the banded ore and 3 of albite-chlorite schists from the Beskes mines were studied. The tectonic diagram for 1 ore sample showed a straight orientation; 2 showed a diagonal orientation; the others failed to show any definite orientation. All three polished sections of the albite-chlorite schists displayed a straight orientation, i.e., with the α^1 axes of the albite grains in a plane parallel to the direction of the banding.

SUMMARY

1. A microscopic study of ores reveals a stage sequence of mineralization, independent of the regional metamorphism. The presence of the mineralization phases, separate in time and space although representing the stages of a single mineralization process, has been confirmed by general geologic data.

2. The pressure in post-ore tectonic pushes was commonly considerable, enough to produce, in individual segments, a regular orientation of sphalerite aggregates with relation to the banding.

3. An irregular, unpredictable orientation of sphalerite grains is more common, which confirms a primary, pre-ore, formation of the banding in the crystallization of ores.

4. However, the coincidence of the optical orientation of albite grains with the banding of albite-chlorite schists testifies to a metamorphic alteration of greenstone rocks.

5. The schistosity and the change in the mineral composition of the enclosing rocks was, on the whole, terminated before the ore making, which is unequivocally attested by the "floating" fragment of these rocks in the ore.

6. The other metamorphic features of the ores have no adequate explanation and remain controversial.

7. The pyrite ore bodies are subsequent to the regional metamorphism. Considering that both the regional low-temperature dynamic metamorphism and the ore making were, by the nature of things, caused by the same tectonic-igneous causes (basement fractures, folding, faulting, injection of magma), and also considering the duration of both processes, a coincidence of the last stages of the regional metamorphism and the onset of ore making is quite probable. This is the explanation of some metamorphic phenomena in the ores, such as crumbling.

8. The intensive tectonic-igneous activity in the Front Range province, and the ore making, occurred in the pre-upper Carboniferous. Accordingly, the object of the search for pyrite ores in the northern Caucasus should be structures including older igneous and sedimentary formations.

REFERENCES

1. Baranov, I. Ya., MINERALOGIYA I PETROGRAFIYA PALEOZOYSKIKH METAMORFICHESKIKH FORMATSIY ZONY PEREDOVOGO KHREBTA NA SEVERO-ZAPADNOM KAVKAZE [MINEROLOGY AND PETROGRAPHY OF PALEOZOIC METAMORPHICS IN THE FRONT RANGE, NORTHWESTERN CAUCASUS]: Rostov Univ. uch. zap., t. 17, vyp. 4, 1952.

2. Bel'kova, L.N., V.N. Ognev and A.I. Semenova, DVE GIPOTEZY O GENEZISE POLIMETALLICHESKOGO ORUDENENIYA NA ALTAYE [TWO HYPOTHESES OF THE POLYMETAL MINERALIZATION IN THE ALTAI]: Akademiya Nauk, USSR, Izv., ser. geol., no. 1, 1954.

3. Bochkovoy, Yu. D., GEOLOGO PETROGRAFICHESKAYA KHARAKTERISTIKA METAMORFICHESKIKH SLANTSEV BASSEYNA REK URUP I LABY NA SEVERNOM KAVKAZE [GEOLOGIC-PETROGRAPHIC DESCRIPTION OF METAMORPHIC SCHISTS IN THE URUP AND LABA BASINS, NORTH CAUCASUS]: Author's thesis, Stalino, 1954.

4. Vakhromeyev, S.A., OPYT PRIMENENIYA STRUKTURNOGO ANALIZA K ISSLEDOVANIYU POLOSCHATYKH KOLCHEDANNYKH RUD [AN APPLICATION OF STRUCTURAL ANALYSIS TO THE STUDY OF BANDED PYRITE ORES]: Gorno-geol. Inst. Ural. fil Akademiya Nauk SSSR, Trudy, vyp. 20, 1953.

5. Grigor'yev, D.P., ZAKONOMERNOSTI

OBRAZOVANIYA SUL'FIDOV MEDI V KOLCHEDANNYKH MESTOROZHDENIYAKH SREDNEGO URALA [PATTERNS IN THE FORMATION OF COPPER SULFIDES AND PYRITE DEPOSITS IN THE MIDDLE URALS]: Vses. mineralog. ob., Zap., t. 82, vyp. 1, 1958.

6. Dena, G., SYSTEM OF MINERALOGY (Translation from English): Izd. Inostr. Lit., 1951.

7. Zavaritskiy, A.N., V.A. Zavaritskiy, T.N. Shadlun, V.P. Loginov, A.V. Pek, S.N. Ivanov and L.G. Kvasha, KOLCHEDANNYYE MESTOROZHDENIYA URALA [PYRITE DEPOSITS OF THE URALS]: Akademiya Nauk SSSR, Izd., 1950.

8. Zavaritskiy, A.N., O GENEZISE KOLCHEDANNYKH MESTOROZHDENIY [ORIGIN OF PYRITE DEPOSITS]: Akademiya Nauk SSSR, Izv., ser. geol., no. 3, 1943.

9. Ivankin, P.F., PO POVODU STAT'I L.N. BEL'KOVOY, V.N. OGNEVA, A.I. SEMENOVOY "DVE GIPOTEZY O GENEZISE POLIMETALLICHESKOGO ORUDNENIYA NA ALTAYE" [REVIEW OF THE PAPER BY L.N. BEL'KOVO, V.N. OGNEV, A.I. SEMENOVA, "TWO HYPOTHESES OF THE POLYMETAL MINERALIZATION IN THE ALTAI"]: Ibid., no. 5, 1954.

10. Ivankin, P.F. and N.M. Mitryayeva, PROTSESS RAZVITIYA MEDNOY I SVINTSOVOTSINKOVOY MINERALIZATSII V SERNYKH KOLCHEDANAKH NIKOLAYEVSKOGO MESOTROZHDENIYA NA ALTAYE [THE PROCESS OF THE COPPER AND LEAD-ZINC MINERALIZATION IN THE NIKOLAYEVSK PYRITES, THE ALTAI]: Ibid., no. 9, 1956.

11. Ivanov, N.V., O GENEZISE KOLCHEDANNOGO MESTOROZHDENIYA NA SEVERNOM KAVKAZE [ORIGIN OF THE NORTH CAUCASUS PYRITE DEPOSIT]: Vses. mineralog. ob., Zap., ch. 82, no. 2, 1953.

12. Ivanov, S.N., NOVYYE DANNYYE O GENEZISE KOLCHEDANNYKH MESTOROZHDENIY SREDNEGO URALA [NEW DATA ON THE ORIGIN OF THE MIDDLE URALS PYRITE DEPOSITS]: Akademiya Nauk SSSR, Izv., ser. geol., no. 1, 1943.

13. Ignat'yev, N.A., GEOLOGO-PETROGGAFICHESKIY OCHERK RAYONA MALOY LABY I YEYE PRITOKOV MARKOPIDZHA I URUSHTENA NA SEVERNOM KAVKAZE [GEOLOGIC-PETROGRAPHIC SKETCH OF THE LITTLE LABA AREA AND ITS TRIBUTARIES, MARKOPIDZH AND URUSHTEN, NORTHERN CAUCASUS]: Akademiya Nauk SSSR, Izd., 1933.

14. Kinoshma Kameki, O GENEZISE MESTOROZHDENIY KUROMONO [ORIGIN OF THE KUROMONO DEPOSITS]: Gos. Geol. Izd., 1932.

15. Lazarenko, Ye. K., O GENEZISE MEDNOTSINKOVYKH MESTOROZHDENIY SREDNEGO URALA [ORIGIN OF THE MIDDLE URALS COPPER-ZINC DEPOSITS]: Lvov Univ. Uch. zap., t. 23, vyp. 6, 1953.

16. Magak'yan, I.G., ALLAVERSKIY TIP ORUDNENIYA I YEGO RUDY [THE ALLAVERDY TYPE OF MINERALIZATION AND ITS ORES]: Akademiya Nauk SSSR, Izd., 1947.

17. Peyve, A.V., OBSHCHAYA KHARAKTERISTIKA, KLASSIFIKATSIYA I PROSTRANSTVENNOYE PASPOLOZHENIYE GLUBINNYKH RAZLOMOV. GLAVNEYSHIYE TYPY GLUBINNYKH RAZLOMOV. [GENERAL CHARACTERISTICS, CLASSIFICATION, AND SPATIAL DISTRIBUTION OF DEEP-SEATED FAULTS. MAIN TYPES OF DEEP FAULTS]: St. 1, Akademiya Nauk, SSSR, Izv., ser. geol., no. 1, 1956.

19. ____________, SVYAZ' OSADKONAKOPLENIYA, SKLADCHATOSTI, MAGMATISMA, I MINERAL'NYKH MESTOROZHDENIY S GLUBINNYMI RAZLOMAMI. GLAVNEYSHIYE TIPY GLUBINNYKH RAZLOMOV ST. 2 [RELATION OF SEDIMENTATION, FOLDING, IGNEOUS ACTIVITY, AND MINERAL DEPOSITS TO DEEP-SEATED FAULTS. MAIN TYPES OF DEEP FAULTS]: St. 2, Ibid., no. 3, 1956.

20. Pek, A.V., STRUKTURA DEGTYARSKOGO MESTOROZHDENIYA I RUDNOGO POLYA LEVIKHI [THE STRUCTURE OF THE DEGTYARSK DEPOSIT AND THE LEVIKHA MINES]: Ibid., no. 1, 1943.

20. Serdyuchenko, D.P., GRANITY BESKESA I MOSHCHEVOY I IKH KONTAKTY SO ZMEYEVIKAMI [THE BESKES AND MOSHCHEVAYA GRANITES AND THEIR CONTACTS WITH SERPENTINES]: Sov. po izuch. proizv. sil i Petrogr. Inst. Akademiya Nauk SSSR, Trudy, ser. sev.-kavkazsk., vyp. 1, 1936.

21. Turner, F.J., EVOLUTION OF META-

MORPHIC ROCKS (Translation): Izd. Inostr. lit., 1951.

22. Shadlun, T. N., OSOBENNOSTI STROYENIYA KOLCHEDANNYKH RUD I IKH METAMORFIZM [STRUCTURAL FEATURES OF PYRITE ORES AND THEIR METAMORPHISM]: Thesis Inst. geol. nauk, Akademiya Nauk SSSR, Trudy, 1954.

23. ___________, O HEKOTORYKH METAMORFICHESKIKH TEKSTURAKH I STRUKTURAKH RUD. [CERTAIN METAMORPHIC TEXTURES AND STRUCTURES OF ORES]: Akademiya Nauk SSSR, Izv., ser. geol., no. 2, 1954.

24. Shcherba, N. G., O DVUKH GIPOTEZAKH OBRAZOVANIYA POLIMETALLICHESKIKH MESTOROZHDENIY RUDNOGO ALTAYA [TWO HYPOTHESES FOR THE POLYMETAL DEPOSITS IN THE RUDNYY ALTAI]: Ibid., no. 5, 1954.

25. Kato Takeo, SOME ORE DEPOSITS IN JAPAN. ORE DEPOSITS AS RELATED TO STRUCTURAL FEATURES: New Jersey, 1942.

North Caucasus Geologic Administration, Krasnodar.

Received September 19, 1958.

BRIEF COMMUNICATIONS[1]

THE MECHANISM OF RADIOGENIC ARGON LOSS IN MICAS[2]

by

Kh. I. Amirkhanov, S. B. Brandt, Ye. N. Bartnitskiy, S. A. Gasanov, and V. S. Gurvich

In the study of the thermal stability of radiogenic (r/g) argon in dispersed micas [1], we determined that low-temperature (150 to 600° C.) losses of such argon occurred in grains as small as 50 to 100 microns (Fig. 1). We believed that these losses were due not to volume diffusion but rather to surface processes similar to desorption. This belief was based on the fact that the liberation of argon was not exponential, as it should have been for diffusion, but was described by an asymptotic curve. For a further development of this view, we studied the temporal regularities in the liberation of radiogenic argon for phlogopite, at various temperatures (sample 150/53, Yakutian A. S. S. R., the Aldan district; M. A. Litsarev collection).

A 0.03 to 0.05 mm phlogopite fraction was used in the study. The samples weighing two grams, were first heated at various temperatures and for various times, then their radiogenic argon content was determined by the mass-spectroscopic method of isotope dilution [2].

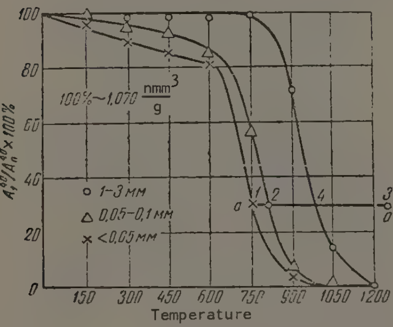


FIGURE 1

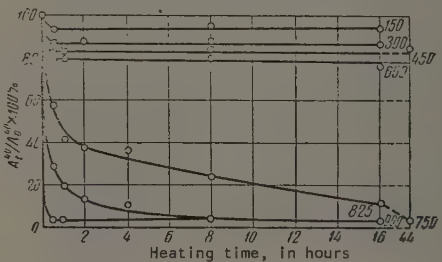


FIGURE 2

The results are given in Fig. 2, which presents two obviously different types of curves, apparently describing two quite different processes. In the curves of type one (at temperatures of 150°, 300°, 450°, and 600° C.), argon is liberated only in the first 30 minutes of heating; then its content remains constant (even at 450° C. for 44 hours). It is obvious that the appreciable losses of argon are caused not by diffusion but rather by desorption proceeding at a considerable rate.

We take for our premise the Langmuir

---

[1] Melkiye soobshcheniya.

[2] O mekhanizme poter' radiogennogo argona v slyudakh.

isotherm

$$\frac{v}{v_M} = \frac{bp}{1 + bp}. \qquad (1)$$

Coefficient b is subject to the following temperature relationship:

$$b = \alpha \frac{e^{q/RT}}{T^{1/2}}. \qquad (2)$$

where v/v_M is the relative amount of the sorbed gas; p is the pressure; a is a numerical coefficient dependent on the properties of the sorbent and the sorbed gas; and q is the sorption heat. Quantity d/R is usually of the order of $10^3\left(\frac{10^{11}}{8,32\cdot 10^7}\right)$. For a preliminary analysis, we assume $\alpha p = 30$. With this assumption, we transform (1) and (2) to fit our case.

$$\frac{A^{40}}{A^{40}_M} = \frac{30\, e^{1000/T}}{T^{1/2}\left(1 + \frac{30\, e^{1000/T}}{T^{1/2}}\right)} \qquad (3)$$

Fig. 3 shows an apposition of the empirical and computed curves, in percent, with the radiogenic argon content of 1.07 nmm^3/g, in the original sample, taken as 100%. The

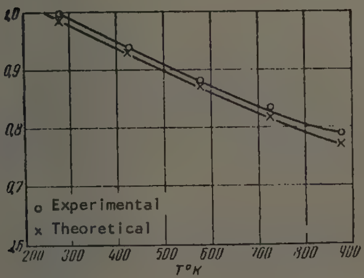


FIGURE 3

divergence between the two curves does not exceed 2 to 3%, which adequate proves that the low-temperature losses (of argon) in micas and in glauconites (3) are not the result of a surface process similar to desorption.

In the curves of type two (at 750°, 825°, and 900° C.), the argon content decreases steadily, approaching a very small residual quantity (3 to 4% of the total content). Judging from the curves, diffusion is possible in this instance. We have shown, however (1), that irreversible processes take place in mica at these temperatures (most likely as the result of the loosening of the structure because of the loss of the constitution water). Consequently, this diffusion does not pertain to mica as such.

For a more rigorous demonstration of the presence of diffusion, the argon liberation curves of type two are drawn on the logarithmic grid (Fig. 4), with straight segments (aa and bb, Fig. 4) which satisfy the diffusion equation

$$\overline{A}^{40} = A_0 \sum_{m=1}^{\infty} \frac{4}{(\mu_0^m)^2} e^{-\left(\frac{\mu_0^m}{r_0}\right)^2 Dt} \qquad (4)$$

where $\overline{A}^{40}$ is the average content of radiogenic argon in a circular mica tablet of radius r_0, at the given temperature; A_0 is the radiogenic argon content in mica, before the heating; μ_0^m is the m root of the Bessel function, zero order, first kind; D is the diffusion constant at the given temperature; and t, the heating temperature.

Using the first harmonic of equation (4),

$$\overline{A}^{40}_1 = \frac{4A_0}{(\mu_0^{(1)})^2} e^{-\left(\frac{\mu_0^{(1)}}{r_0}\right)^2 Dt}, \qquad (5)$$

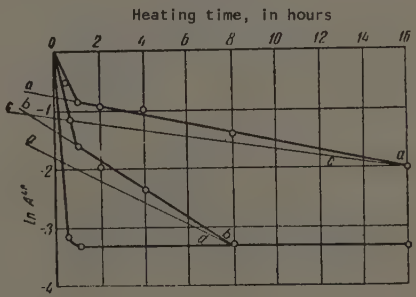


FIGURE 4

D may be determined from the slope of the straight line.

Our determinations are made on the following assumptions. At the initial instant, the amplitude of the first harmonic is $\frac{4}{(\mu_0^{(1)})^2}$ times smaller than the corresponding value of $\overline{A}^{40}$. At the terminal instant, all higher harmonics have been dampened to such an extent that all A^{40} [sic] values may be taken as equal to that of the first harmonic. Consequently, the straight lines determining the first harmonic (cc and dd, Fig. 4) lie below

the corresponding segments of the experimental lines. Then,

$$D = -\frac{1}{\left(\frac{\mu_0^{(1)}}{r_0}\right)^2} \cdot \frac{\Delta(\ln \bar{A}_1^{40})}{\Delta t}. \qquad (6)$$

In our case, the average value of r_0 is 0.02 mm. Obtained in the same way were the values of $D_{750°} = 1.2 \cdot 10^{-11}$ cm²/cek and $D_{825°} = 3.8 \cdot 10^{-11}$ cm²/cek.

D_{900^0} has not been computed, because of its fairly large value, which would make it impossible to distinguish between diffusion and desorption. Using this pair of values and the relationship

$$D = D_0 e^{-\frac{E}{RT}}, \qquad (7)$$

the activation energy E can be computed. It came out to be 35,000 cal/mole. The value obtained for phlogopite by E. K. Gerling [7] was 67,000 cal/mole. Considering that these figures were obtained not only with different measuring methods but also with quite different mathematical procedures, they should be accepted as being in substantial agreement.

It should be also noted, that our figure pertains directly to argon, having been computed from its diffusion constants. The figure 67,000 cal (5), on the other hand, refers to the sum total of all volatiles which are liberated from phlogopite at the given temperatures. Consequently, its association with argon alone is arbitrary.

Using (7), the value of D can be extrapolated for the standard temperature: $D_{273°} = 10^{-31}$ cm²/sec. We have shown that mica undergoes irreversible changes at this temperature interval. It may be expected, therefore, that the true value of D, at the standard temperature, will be considerably smaller.

It has been shown (4) that the volume diffusion of radiogenic argon is impossible, because of "external" causes. Now we arrive at the conclusion that it is impossible also because of an "internal" cause: the extremely small value of D. Indeed, it has been shown in our paper [6] that the effect of diffusion is determined by the commensurability of factor

$$\left(\frac{\mu_0^{(m)}}{r_0}\right)^2 \frac{D}{\lambda}$$

with a unit (λ is the constant of the potassium radioactive transformation). For $\mu_0^{(3)}$ and $r_0 = 1$ micron, this factor comes to 10^{-4}, i. e., there is no diffusion even with this radius of the mica plate.

The validity of these theories and of the values of D and E so obtained can be verified by computing the temperature shift in the argon liberation curves from different phlogopite fractions. The following obvious equality holds true for points on the curves, along the straight line parallel to the horizontal axis (Fig. 1):

$$A_n e^{-\left(\frac{\mu_0^n}{r_{01}}\right)^2 D_t e^{-\frac{E}{RT_1}}} = A_n e^{-\left(\frac{\mu_0^n}{r_{02}}\right)^2 D_t e^{-\frac{E}{RT_2}}}$$

And after some elementary transformations:

$$\left(\frac{r_{02}}{r_{01}}\right)^2 = e^{\frac{E}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)}. \qquad (8)$$

For the average fraction radii of 0.02, 0.038, and 1 mm, the corresponding temperature shifts will be from 750° to 830° C. (from point 1 to point 2, Fig. 4) and 1600° C. (from point 1 to point 3, Fig. 4). The first interval coincides exactly with the experimental shift, whereas the second is somewhat larger. This is because the destruction of the phlogopite structure begins at about 1050° C., with a consequent increase in diffusion. As a result, the experimental curve has been shifted toward lower temperatures (from point 1 to point 4, Fig. 4).

CONCLUSIONS

1. The loss of radiogenic argon from micas, at temperatures as high as about 600° C., is a result of desorption type processes and is adequately described by the Langmuir isotherms.

2. The argon losses in micas, because of diffusion, become appreciable only at temperatures higher than about 600° C.

3. At standard temperatures, the diffusion coefficient in micas should not exceed 10^{-31} cm²/sec.

REFERENCES

1. Amirkhanov, Kh. I., S. B. Brandt, Ye. N. Bartnitskiy, V. S. Gurvich, S. A. Gasanov and V. S. Ivanov, TERMICHESKAYA USTOYCHIVOST' RADIOGENNOGO ARGONA V DISPERSNYKH SLYUDAKH [THERMAL STABILITY OF RADIOGENIC ARGON IN DISPERSED MICAS]: Sborn. Sokhrannost' radiogennogo argona. Makhachkala, 1958.

2. Amirkhanov, Kh. I. and S.B. Brandt, OPREDELENIYE ABSOLYUTNOGO VOZRASTA POROD [DETERMINATION OF THE ABSOLUTE AGE OF ROCKS]: Makhachkala, 1956.

3. Amirkhanov, Kh. I., S.B. Brandt, Ye. N. Bartnitskiy, V.S. Gurvich and S.A. Gasanov, K VOPROSU O SOKHRANNOSTI RADIOGENNOGO ARGONA V GLAUKONITAKH [THE PROBLEM OF PRESERVATION OF RADIOGENIC ARGON IN GLAUCONITES]: Akademiya Nauk SSSR, Dokl., t. 118, p. 328, 1958.

4. Amirkhanov, Kh. I., S.B. Brandt and Ye. N. Bartnitskiy, O NEKOTORYKH VOPROSAKH TEORII ARGONOVOGO METODA [SOME ASPECTS OF THE ARGON METHOD THEORY]: Sb. Sokhranennost'radiogennogo argona, Makhachkala, 1958.

5. Gerling, E.K. and Morozova, I.M., OPREDELINIYE ENERGII ACTIVATSII VYDELENIYA ARGONA IZ SLYUD [DETERMINATION OF THE ACTIVATION ENERGY OF THE ARGON LIBERATION FROM MICAS]: Geokhimiya, no. 4, 1957.

6. Amirkhanov, Kh. I., S.B. Brandt, Ye. N. Bartnitskiy, L.K. Anokhina and V.S. Ivanov, K VOPROSU O DIFFUZII RADIOGENNOGO ARGONA V SLYUDAKH [THE PROBLEM OF RADIOGENIC ARGON DIFFUSION IN MICAS]: Sb. Sokhrannost' radiogennogo argona. Makhachkala, 1958.

The Daghestan Branch of
the Academy of Sciences, U.S.S.R.
Makhachkala

Received June 5, 1958

A.N. WINCHELL MEMORIAL (1874-1958)[1]

Alexander Newton Winchell, Professor Emeritus of mineralogy, passed away after a short illness, on June 7, 1958, at New Haven. He was 85 years old.

The name of A. N. Winchell is well known to all mineralogists and petrographers, chiefly because of his three-volume manual, "Principles of Optical Mineralogy," of which volume two, dealing with the description of minerals, has been twice published in Russian. In addition, A. N. Winchell was the author of more than 100 scientific works reflecting the wide scope of his interest.

A. N. Winchell was born on March 2, 1874, in Minneapolis, Minnesota, to the family of a geologist.[2] He received his A. B. degree in 1896, and then his degree in petrography. He went to France in 1898 to work for two years with the famous Professor Lacroix. Here he defended his doctor's thesis on the petrography and mineralogy of the Minnesota gabbroids (Etude mineralogique et petrographique des roches gabbroiques de l'Etat de Minnesota. Univ. Paris These. Paris, 1900).

Upon his return, he taught geology and mineralogy at the Butte, Montana School of Mines, until the end of 1907. In 1908 he was appointed Professor of Mineralogy and Petrology at the University of Wisconsin, Madison, Wisconsin. Here he spent many years as a scientist, administrator, and teacher, and wrote his manuals and handbooks familiar to most mineralogists.

With his outstanding administrative abilities, A. N. Winchell took an active part in many scientific societies and committees. In 1930 he was appointed Chairman of the National Scientific Research Committee for Accessory minerals, in which capacity he served seven years. In 1932 he was elected President of the Mineralogical Society.

From 1934 to 1940 he was Director of the Geology Department, University of Wisconsin, and retired in 1940 on his seventieth anniversary to become Professor Emeritus after 37 years of teaching. He then moved to Hamden, a quiet town seven kilometers north of New Haven, Connecticut where he was elected Honorary Member of the Yale University Geological Department.

Despite his advanced age he accepted, in 1945, the position of Resident Consultant for the Stamford Cyanamide Research Laboratory. He taught for two years, first at the University of Virginia, then at Columbia. After having finally abandoned teaching, he still continued his scientific work. In 1951, he published (with the assistance of H. Winchell) the fourth edition of "Principles of Optical Mineralogy," vol. II; and in 1954 he rewrote

---

[1] Pamyati A. N. Vinchella (1874-1958).

[2] Some of the biographical data were kindly put at my disposal by Prof. Horace Winchell, son of the deceased.

nd published his "Optical Properties of rganic Substances."

From January to March 1958, shortly efore his death, A.N. Winchell made a trip o Africa, from Cape Town to Cairo. Shortly fter that he visited the Soviet Union, but as unable to see the Crimea and the Cau-asian Black Sea shore, as he had wanted. fter several days in Moscow, he became l and had to return to Hamden. From there e was moved to a New Haven hospital where e died in a few days.

The scientific works of A.N. Winchell umber 112, not counting the reviews of uropean works and numerous articles for e Britannica and chemical encyclopedias. ineralogy was his main field of work. For ore than a half a century he chiefly studied e relationship between the chemical com-osition of minerals and their optical proper-ies. About half of his works deal with this ubject.

A.N. Winchell first became interested in ptical mineralogy while working at the Paris niversity where the microscopic study of inerals, under A. Michel-Levi, was con-ucted at a high level. The prevailing con-emporary mineralogic opinion was that min-rals had a fixed composition with correspond-ng fixed established properties. To be sure, e idea of isomorphous crystal displacement, olstered by G. Chermak's work on the com-osition of complex silicates, gained in pop-larity among those who regarded minerals s natural products with a variable composi-ion. A.N. Winchell attempted a graphic emonstration of the relationship between the ariable composition of minerals and their orrespondingly variable optical properties. n the first edition of his "Elements of Opti-al Mineralogy," 1909, however, he only ave two composition-property diagrams for plagioclases and the orthoclase-sanidine ystem), where the extinction angle 2V and he specific weight were cited along with the efraction index. In the twenties, he under-ook a systematic study of the chemical com-ositions and properties of individual mineral roups, chiefly the silicates.

In his study of the mineral properties as function of their composition, A.N. Win-hell often emphasized the approximate nature f the data in the diagrams, inasmuch as the onstant contamination by foreign elements, ommonly barely detectable by chemical nalysis (and not reflected in the diagrams), ppreciably affected their physical properties. t is known that absolute purity can be achieved in synthetic compounds, which may be used for a more precise correlation between the composition and the properties of a compound. Carrying out this idea, A.N. Winchell, in 1927, compiled a manual of optical properties for the so-called synthetic minerals. He enlarged and supplemented it in the second edition, 1931 (see translation; D.S. Belyankin, Editor: A.N. Winchell. Optics and Microscopy of Synthetic Minerals. Gos. Khim. Tekh. Izd., 1933).

For many years A.N. Winchell defended the idea that most minerals are natural bodies with a wide composition range. He believed this to be the main premise of modern mineralogy, and he so stated as early as 1933 in his paper, "The New Mineralogy" (Am. Min., v. 18, no. 3, 1933, pp. 81-90). He favored a broader interpreta-tion of what constituted a mineral, believing that a mineral should include all samples connected through the continuity of changes in their chemical composition. This inter-pretation has been accepted by many mineral-ogists. However, because mineral nomen-clature still was tied to a narrow range, A.N. Winchell had to introduce a number of new names, as explained in his "Elements of Mineralogy Emphasizing the Variations in Minerals," (New York, 1942) and especially fully in his paper, "What is a mineral?" (Am. Min. v. 34, No. 3-4, 1949, pp. 220-225). Thus "brown spar" is the name for the composition (Mg, Fe, Mn, Zn)CO_3; "ensten-ite" for (Mg, Fe)SiO_3; "ugrandite" for $Ca_3(Cr, Al, Fe)_2[SiO_4]_3$, etc. These names, as is the case of most new terms, have not gained popularity with mineralogists.

When X-ray study was introduced, A.N. Winchell did not only take cognizance of it, as did some of his fellow mineralogists. In 1934, he set out to learn the new technique. At the California Institute of Technology, Pasadena, he determined the structure of swedenborgite in cooperation with L. Pauling (Am. Min., v. 20, No. 8, 1935, 492-501). In Manchester he studied the subject with W. Bragg and W. Taylor. This enabled him to improve his mineral systematics on a crystallographic chemical basis.

The life of A.N. Winchell was marked by vigorous scientific activity. He was a mem-ber of many scientific institutions. In recog-nition of his achievements he was awarded the 1955 Roebling Medal by the American Mineralogical Society.

A.S. Povarennykh.

REVIEWS AND DISCUSSIONS[1]

TYPES OF CARBONATITE DEPOSITS AND THEIR RELATION WITH ULTRABASIC TO ALKALINE MASSIFS[2]

by

N.A. Volotovskaya and A.A. Kukharenko

This was the title of an interesting paper by L.S. Borodin (Izvestiya, Ser. Geol., no. 5, 1957) on a number of important problems in the geology and petrology of pyroxenite-iolite intrusions and associated carbonate rocks with a rare-metal mineralization. In the first part of the paper, the author gives a general review of the geologic position of carbonatites, chiefly in foreign localities, and outlines a sequence of petrographic series, progressively more complex, which carry these carbonatites. This portion of the paper, presenting as it does the voluminous and diversified material recently published on carbonatites, is of unquestionable interest.

In the second part, L.S. Borodin attempts to clarify the formation mechanism for the complex ultrabasic and alkaline massifs and of the processes leading to the formation of carbonatites. He considers most complicated the petrologic problems of the Kola Peninsula and north Siberian ultrabasic and alkaline massifs.

We shall leave the judgment of the author's theories as applied to the Siberian massifs (Odikhinch, Kugd, etc.) to other geologists who have firsthand knowledge of those localities. As for the Kola intrusions, the basic premises of L.S. Borodin on the origin of alkaline rocks, their relationship with the ultrabasics, the origin of the rare metal mineralization, etc., are most decidedly open to criticism.

L.S. Borodin states fairly categorically that alkaline rocks participating in the structure of these multiphase Kola massifs are not of an igneous origin. He writes (p. 9), "A petrographic study of the alkaline zones in a number of massifs shows that the geologic-petrographic relationship of these rocks with pyroxenites, as well as their textural-structural features, preclude the possibility of the formation of nepheline-pyroxene rocks as a result of an injection and a more or less simultaneous crystallization of a 'nepheline-pyroxene' magma." According to L.S. Borodin, alkaline rocks -- "mel'teygity", iolites, urtites, etc. -- are formed in the Kola and similar intrusions as a result of a postigneous "nephelinization" of pyroxenites. He sees proof of that, first in the fact that "the alkaline zones pyroxene is usually similar in its basic molecule to that of the pyroxenite zone;" and second, in the diversity of the alkaline rocks composition, and the irregular disposition of segments with a different pyroxene and nepheline content. The author also cites the evidence of the subhedral (granoblastic, according to L.S. Borodin) texture of alkaline rocks and the presence of pyroxene inclusions in nepheline.

According to L.S. Borodin, the nephelinization of pyroxenes results in "the displacement of 30 to 50 percent pyroxene from the original rock." Calcium, magnesium, and iron are leached out in the process, which results in a development of calcium metasomatism (apatitization of pyroxenites, amphibolization of monoclinic pyroxene, perovskitization of titanomagnetite, etc.) and magnesium metasomatism (phlogopitization of pyroxenites). As a final result, there originates a motley series of rocks, from the apatite-olivines to carbonates. The rare metal mineralization, associated with these rocks, is also genetically related to alkaline solutions which come from the "nephelinization" zones.

It should be noted that some of the processes mentioned by L.S. Borodin (phlogopitization, carbonatization) did take place in the Kola-Peninsula complex ultrabasic and alkaline massifs. These phenomena have been noted and described in detail in numerous unpublished

[1]Kritika i diskussii.

[2]O tipakh karbonatitovykh mestorozhdeniy i ikh svyazi s massivami ultraosnovynykh-shchelochnykh porod.

eologic, petrologic, and mineralogic works. owever, the basic contention of L.S. Borodin, n the origin of iolites, "mel'teygity," and ther alkaline rocks in the multiphase Kola assifs, in the process of "nephelinization" f pyroxenites, accompanied by perovskitiza- on, apatitization, and other processes; tands in irreconcilable opposition to the normous factual material accumulated in the any years of geologic surveys, reconnais- ance, and the petrographic-mineralogical tudy of these massifs. None of the petrog- aphers and mineralogists who studied these eologic bodies during the course of years N.G. Kassin, B.M. Kupletskiy, P.N. Chir- inskiy, V.S. Sobolev, N.D. Sobolev, Ts.G. latkind, M.S. Afanas'yev, V.A. Afanas'yev, .G. Ushakova, O.M. Rimskaya-Korsakova, .N. Bel'kova, the authors of this paper, and any others), has succeeded in observing ese phenomena, very common according to .S. Borodin. On the contrary, the field data om hundreds of natural and man-made out- rops, and thousands of samples and thin ections, leave no ground for the assumption f a metasomatic nature of iolite, a post- gneous origin of perovskite in the olivine and yroxene ores, and of other phenomena de- cribed by L.S. Borodin.

Alkaline rocks from all the massifs which ave been studied in detail, belong to a late ntrusive phase. They have typically intrusive ontacts with earlier ultrabasic rocks (pyrox- nites, less commonly olivinites and perido- ites); they cut the latter in veins; carry umerous pyroxenite xenoliths; pierce the nclosing Archaean gneisses and gneiss- ranites in a number of veins, apophysis, tc,; i.e., they exhibit all the features of ommon intrusives.

Similar relationships between ultrabasic nd iolite-"mel'teygit" rocks have been ecorded in the Vuori-Yarvin, Bol'shoy Kov- or, Salmagor, and Ozernaya Varaka massifs; imilar relationships have also been estab- ished between vein alkaline rocks (nepheline egmatites, pegmatoid iolites) and pyroxenites n the massifs of Africanda, Vuori-Yarvi, ubl'-Yarvi, Lesnaya Varaka, and elsewhere.

In those intrusive bodies where iolites and mel'teygity" form outer contact zones, these ocks exhibit all the structural-textural evi- lence of their igneous nature: the plane and inear orientation of pyroxene prisms and epheline tablets, equally participating in the novement of the silicate solution; the trachy- oid orientation of pyroxene and nepheline rystals, concordant with the contact surface bout the large xenoliths of gneiss and, in laces, of pyroxenite, etc. All these obvious eatures have been described many times; and heir interpretation as a proof of a metaso- natic origin of alkaline rocks means a complete negation of the generally accepted facts of geology and petrography. An even more complex relationship has locally been established between pyroxenites and iolites, such as the formation of arteric migmatites at their contacts, accompanied by an intensive amphibolitization, biotitization, and phlogopiti- zation of pyroxene, by sphenization of perov- skite and the pyroxene titanomagnetite, and by a local development of garnet, vesuvianite, and mililite. However, even these relation- ships, substantially similar to the familiar contact phenomena for most diversified intru- sives (from granite to gabbroids and ultra- basics) and the enclosing rocks cannot be used as a proof of the "nephelinization" hypothesis.

Nor can be regarded as a proof, the un- even distribution of dark components and of nepheline, familiar in the "mel'teygit"- urtite series of alkaline rocks, as well as their tendency for the formation of glomero- plasmatic-crystalline textures. Such textures are proper to most "mel'teygity" and iolites, regardless of the conditions of their occur- rence. Specifically, they have been described for the Khibin iolite-urtites; in late Paleo- zoic dikes of tinguaite, nephelinites, and other nepheline-pyroxene vein rocks of the Tersk coast area, Turiy Peninsula, and other localities. They are in no way indicative of the "nephelinization" phenomena.

Nor indicative of that is the similarity of the "basic molecule" of pyroxene from iolite with that from pyroxenite, emphasized by L.S. Borodin. First of all, the "similarity" is not that great, because pyroxenes carry titaniferous diopside-augite, whereas iolites carry acmite-diopside (acmite-augite); sec- ond, except for the alkaline representatives, monoclinic pyroxenes in all rocks, from gab- broids and basic extrusives to ultrabasics, crystalline schists, and even the Alpine-type veins, are characterized by a "similar" basic molecule (the preponderance of diopside- hedenbergite).

The inconsistency of L.S. Borodin's con- tention of the origin of alkaline rocks as a result of a hypothetical "nephelinization" of pyroxenites is also exposed by the existence of independent "mel'teygit"-iolite intrusions (massifs and dikes) known from the southern (Kandalaksha) belt of lower Paleozoic ultra- basic and alkaline massifs.

The same is true for the L.S. Borodin contention of a metasomatic nature of perov- skite and apatite in ultrabasic rocks of the massifs under consideration. Perovskite (knopite), which is an important rock-forming mineral in olivinites and pyroxenites, is accumulated, together with titanomagnetite, in ore-bearing varieties of these rocks,

especially in "schlieren" of olivinites. It should be noted that in those massifs where alkaline rocks (the "nephelinization" processes of L.S. Borodin) are not developed as such, knopite has been best developed (ore-bearing olivinites of Africanda and Lesnaya Varaka). Everywhere in olivinites and pyroxenites, knopite crystallized after silicates and prior to titanomagnetite, which has led to most typical sideronitic textures. In banded olivinites, knopite and the xenomorphic titanomagnetite separates, which cement the knopite crystals, form isolated ore layers completely subordinate to the overall rock structure. In segments of a subsequent alteration of pyroxenites, knopite as well as pyroxene and titanomagnetite become unstable and are replaced by sphene, anatase (octahedrite), ilmenite, and other secondary minerals.

There are known instances of a postigneous redeposition and collective recrystallization of knopite, such as in amphibole-calcite-diopside rocks of the Africanda massif; in areas of recrystallized pyroxenites in the northern part of that massif, and in a few other instances. However, even there the behavior of knopite is in no way different from that of silicates and magnetite, which also have undergone redeposition and a collective recrystallization, as proven by their structural features and by the textural relationship of their component minerals.

The problem of the origin of alkaline rocks, of the nature of knopite in pyroxenites and olivinites of the massifs, and similarly to the multiphase Kola intrusions, is by no means one of those theoretical problems which abound in petrology. This is the foremost problem in exploration, inasmuch as it is by no means irrelevant, in the evaluation of rare-metal prospects whether their Nb, Ta, Zr, and other elements have been added from deep-seated solutions, in the process of "nephelinization," or whether they are indigenous to the ultrabasic and alkaline rocks themselves. A logical consequence of L.S. Borodin's contention is the futility of looking for rare metals in those massifs which do not show any "nephelinization" (the development of alkaline rocks) and, conversely, the recognition as best prospects, of those essentially alkaline intrusions where this process did have the maximum development.

Another conclusion, however, is suggested by the extensive chemical-analytical and mineralogical data on alkaline and ultrabasic rocks of the Kola Peninsula: Nb, Ta, Tr, Zr, Hf and other rare elements in ultrabasic rocks themselves are concentrated here in knopites and to a smaller extent in titanomagnetite and silicates. Industrial concentrations of these elements in apatite-forsterite-magnetite ores and in phlogopite-magnetite-calcite, actinolite-calcite, and carbonate rocks have originated as a result of complex processes of liberation of these elements, their migration, and accumulation in metasomatic rocks of a post-igneous stage. As to the iolite-"mel'teygit" rock series, they do not carry any concentrates of Nb, Ta, Zr, and other rare elements. As yet, no ore shows of any importance have been found associated with the massifs of alkaline rocks proper, in the lower Paleozoic igneous sequence of the Kola Peninsula.

True, the author mentions the association of alkaline rocks with pyroxenites in the massifs. This, however, is a restatement of well-known facts and is in contradiction to his conception.

Much remains unclear in the problem of the origin of rare-metal deposits genetically related to igneous complexes of ultrabasic and alkaline rocks. There is much to be done toward an understanding of the role of individual rocks in the structure of these multiphase intrusions, of the sequence of their mineral parageneses, of the behavior of rare elements on different stages of the massif formation, etc. Both a theoretical analysis of the data and their generalization into a hypothesis are necessary. However, premature concepts, original and advanced as they may appear, are hardly a help in the solution of this problem, if they go against the known facts. Such are, in many respects, the concepts in L.S. Borodin's paper.

Received November 16, 1957

A FEW REMARKS ON THE PAPER OF L.S. BORODIN, "TYPES OF CARBONATITE DEPOSITS AND THEIR RELATION WITH ULTRABASIC TO ALKALINE MASSIFS"[3] [4]

by

B.I. Serba

The main thesis of L.S. Borodin's paper is: "Carbonatites include only those carbonate rocks associated with the metasomatic alteration of ultrabasic rocks, and first of all with the process of "nephelinization." In other words, L.S. Borodin relates the formation of

---

[3]Izvestiya Akademiya Nauk, U.S.S.R., ser. geol. no. 5, 1957.

[4]Nekotoryye zamyechaniya k stat'ye L.S. Borodina "tipakh karbonatitovykh mestorozhdeniy i ikh sviazi s massivami ultraosnovnykh shchelochnykh porod."

carbonatites with the nephelinization of ultrabasic rocks, wherein as much as 30 to 50 percent pyroxene, usually $Ca(Mg, Fe)Si_2O_6$, is replaced in the original basic rock. Such components as calcium, magnesium, and iron are leached out of the nephelinization zone as solution products. At the last stages of the process, when the concentration of alkalis decreases in the essentially carbonate solutions, calcium and magnesium are accumulated. However, calcium is bound in a calcite or bicarbonate molecule, which ultimately leads to the formation of carbonate rocks. This, in short, is the essence of L.S. Borodin's theory.

Carbonatites are known to extend over areas of several square kilometers [1, 2, 3]. The depth of their occurrence in columnar, stocklike bodies is not definitely known, because the depth of the massifs themselves is not known, but it exceeds many hundreds of feet [1, 3]. Consequently, the volume of carbonatites in some of the massifs may be several cubic kilometers. To produce such a comparatively large volume, a 10 to 15 times larger volume of ultrabasic rocks is necessary, according to the L.S. Borodin theory. These values were obtained by the following computations: in the decomposition of pyroxene, $Ca(Mg, Fe)Si_2O_6$, 40.08 (atomic weight of calcium) volume units of calcium are obtained from 272.37 (gram-molecule of pyroxene) units of pyroxene, or one unit of calcium to 6.7 units of pyroxene. Only 30 to 50 percent pyroxene of the original rock is removed, which makes the original volume 2 to 3 times larger. In other words, 13.4 to 20.1 volume units of ultrabasic rocks are necessary to produce one unit of calcium.

Let us assume that a carbonatite is 80 to 85 percent pure calcium, with the molecular weight of 100.08. Then, the above-named volumes of ultrabasic rocks should be decreased by 3 to 5 units.

Consequently, 10 to 15 volume units of original ultrabasic rock are needed to produce one unit of carbonatite. In addition, calcite in the amount of fractions of one percent to as much as 10 percent by volume, is present in alkaline rocks of the jacupirangite-urtite series. According to L.S. Borodin, it also must have been formed in the "calcium" metasomatism.

Furthermore, "In intensive 'calcium' metasomatism, a zone of apatite-pyroxene rocks originating in the apatitization of pyroxenite appears between the unaltered pyroxenites and nepheline-pyroxene rocks." In other words, a part of the calcite, which originated in the "nephelinization of pyroxenites," was expended in the formation of apatite, since the metasomatic solutions brought in only the alkalis, aluminum, phosphorus, and other components, but not calcium, magnesium, iron, etc. It follows that the volume of original ultrabasic rocks must exceed that of carbonatites by a factor even greater than indicated above. However, we shall disregard this last correction.

To check this conclusion, we have computed the volumes for both carbonatites and

No.	Name and location of massif	Area, km^2		Volume, km^3		Carbonatites—alkaline rocks volume ratio
		Carbonatites	Alkaline rocks	Carbonatites	Alkaline rocks	
1	Fen (Norway)	2	2.2	0.2	0.22	1:1
2	Spitzcop (South Africa)	1.5	8.0	0.15	0.8	1:5
3	Lulicop, (Africa)[a]	0.4	1.6	0.04	0.16	1:4
4	Bukusu (Africa)	3.5	13	0.35	1.3	1:3.7
5	Magnet Cove (U.S.A.)[b]	0.18	2.5	0.018	0.25	1:14
6	Shava (South Rhodesia)[c]	8.0	32.0	0.8	3.2	1:4
7	A large intrusion (U.S.S.R.)	6.4	5.0	0.64	0.5	1.2:1
8	Carbonatite massif (U.S.S.R.)	3.12	3.6	0.31	0.36	1:1.1

[a] Metasomatically altered rocks here are pyroxene-vermiculite-olivine and magnetite-aplite-olivine.
[b] The area of alkaline rocks, after Yu. M. Sheynmann's map; that of carbonatite, after W.H. Pecora [2].
[c] Numerical data on the areas, after W.H. Pecora [2].

alkaline rocks for those massifs for which geologic maps are provided in the papers of L.S. Borodin [1] and Yu.M. Sheynmann [3]. The area was taken from the map; the depth was assumed to be 100 m. The results are given in the table on the preceding page.

Because of the small scale of the maps, these results are not too precise. They show, however, that only the Magnet Cove massif shows a carbonatite-alkaline rock ratio in agreement with the L.S. Borodin theory. It should be kept in mind that only the volume of the main carbonatite body has been computed from its dimensions as given in the W.H. Pecora paper [2].

According to Pecora, several additional dikelike bodies of carbonatites are present in that locality. Their dimensions are not given and they have not been included in the computation. In the other massifs, the true ratio is far from the computed one.

It is possible that L.S. Borodin's theory explains the formation of small dikelike carbonatite bodies. It does not hold true for all six types (after L.S. Borodin) of carbonatite deposits.

REFERENCES

1. Borodin, L.S., O TIPAKH KARBONATITOVYKH MESTOROZHDENIY I IKH SVYAZI S MASSIVAMI ULTRAOSNOVNYKH SCHELOCHNYKH POROD [TYPES OF CARBONATITE DEPOSITS AND THEIR RELATIONS WITH ULTRABASIC TO ALKALINE MASSIFS]: Akademiya Nauk SSSR, Ser. Geol., no. 5, 1957.

2. Pecora, W.H., CARBONATITES: Trans. from English by Yu.M. Sheynmann. Obzor. iz zarubezhnykh zhurnalov, vyp. 2, Moscow. Min. Geol. i Okhr. Nedr, 1957.

3. Sheynmann, Yu.M., NEKOTORYYE GEOLOGICHESKIYE OSOBENNOSTI ULTRAOSNOVNYKH I ULTRASHCHELOCHNYKH MAGMATICHESKIKH OBRAZOVANIY NA PLATFORMAKH [SOME GEOLOGIC FEATURES OF THE PLATFORM ULTRABASIC AND ULTRA-ALKALINE FORMATIONS]: Vses. miner. Ob. Zap., ser. 2, ch. 84, vyp. 2, 1955.

Received May 16, 1958

THE PAPER OF I.S. CHUMAKOV, "THE REMAINS OF MARINE DIATOMS IN CONTINENTAL CENOZOIC DEPOSITS OF THE GORNYY ALTAI AND THE PALEOGENE SEA BOUNDARY IN THE SOUTH OF WESTERN SIBERIA"[5, 6]

by

G.G. Martinson

The author raises the question of the reason for the presence of cells of marine diatomaceous algae in continental deposits of the Gornyy Altai and the adjacent areas. In rejecting the possibility of their transfer by surface streams in the erosion of older marine deposits, he sides with the eolian transfer theory.

However, the paper ignores an explanation which we believe to be the most plausible.

The occurrence of Tertiary and Quarternary brackish water and marine diatoms is not uncommon. For instance, A.A. Zhuravleva and V.S. Poretskiy [2] identified numerous diatomaceous algae from lacustrine Miocene deposits of the Tunkin trough, the Trans-Baikal region. Among them were such marine and brackish water forms as Coscinodiscus bathyomphalus Cl., C. elegans var. inermis (Pant), C. intersectus Brun., Diploneis smithii Breb, etc. It should be noted that no marine Tertiary deposits are present in that area of eastern Siberia.

A peculiar diatom assemblage was identified by A.P. Zhuze [1] from the Far-East Tertiary (the area of Lake Khanka). Marine diatoms were also noted in the Karelian Quaternary continental deposits.

These facts point to the existence of some marine and brackish water diatoms in fresh waters of ancient basins.

The presence of simple marine organisms in fresh waters is not limited to diatoms. According to O.I. Shmal'gauzen [4], multicameral foraminifera of the genus Borovia are present in the Balpash-Sor lake, Kazakh. S.S.R. We have found multicameral Discorbis [3] in Miocene continental deposits of the east Baikal region.

What, then, was the situation in the Rudnyy Altai and the Pavlodar Irtysh areas?

---

[5] Akademiya Nauk U.S.S.R., Doklady, t. 121, no. 3, 1958.

[6] K stat'ye I.S. Chumakova "ob ostatkakh morskikh diatomey v kontinental'nykh kaynozoyskikh otlozheniyakh rudnogo altaya i granitse paleogenovogo morya i na yuge zapadnoy sibiri."

According to A.L. Yanshin, V.V. Lavrov, K.V. Nikiforova, and many others, the Turgai seaway developed in the Eocene and early Oligocene. In the middle Oligocene, the sea began to recede. The marine Chegan formation gave place to continental deposits of the Kutanbulak, Chilitinsk, and Zhaksyklych formations, overlain by the upper Oligocene Chagraisk formation, also of a continental origin. They are followed by the Aral (lower to middle Miocene) and Pavlodar (upper Miocene to lower Pliocene) formations.

As the marine basin area contracted, a number of residual lakes was formed which preserved some elements of the marine fauna and flora. A further freshening of these lakes imperiled some of the lagoonal forms, while the others accomodated to the new environment. Thus, new relict marine forms came into being.

It is of interest that fossil molluscs of these continental sequences, too, exhibit appreciable differences. Gastropods of the Zhaksyklych formation are still represented by some brackish forms, nearly absent in the higher Chagraisk and Aral formations.

An explanation of the occurrence of marine diatoms in the south of western Siberia hardly lies in an eolian transportation of the entire microfauna and flora assemblage. The algae in question are most likely marine relicts left behind in the Neogene lacustrine basins by the retreating Turgai Sea.

REFERENCES

1. Zhuze, A.P., K ISTORII DIATOMNOY FLORY OZERA KHANKA [THE HISTORY OF THE LAKE KHANKA DIATOM FLORA]: Inst. geogr. Akademiya Nauk SSSR, Trudy, Vyp. 51, 1952.

2. Zhuravleva, A.A., ISKOPAYEMYYE DIATOMOVYYE TUNKINSKOY KOTLOVINY (PRIBAIKLA'YE) [FOSSIL DIATOMS OF THE TUNKIN TROUGH (BAIKAL REGION)]: Neft. Geol. razv. inst., Trudy, ser. A, vyp. 76, 1936.

3. Martinson, G.G., MATERIALY K ISSLEDOVANIYU ISKOPAYEMOY MIKRO- I SPONGIOFAUNY PRIBAIKAL'YA [MATERIALS FOR THE STUDY OF MICROFAUNA AND SPONGES OF THE BAIKAL REGION]: Baikal. limnol. st. Akademiya Nauk SSSR, Trudy, t. 10, 1940.

4. Shmal'gauzen, O.I., FORAMINIFERY IZ SOLENOGO OZERA BALPASH-SOR [FORAMINIFERA FROM THE BALPASH-SOR SALT LAKE]: Labor. sapropel. otlozh. Akademiya Nauk SSSR, Trudy, vyp. 5, 1951.

Received May 16, 1958

THE PAPER OF A.B. VISTELIUS, "NEW CONFIRMATION OF GOLDSCHMIDT'S OBSERVATIONS ON THE POSITION OF GERMANIUM IN COALS"[7,8]

by

V.M. Yershov

Twelve years ago, A.B. Vistelius considered the relationship of germanium with the ash content in coals. There is an error in his paper, which, as far as we know, has not been noticed.

Using data of V.M. Ratynskiy (Trudy Biogeoknim. labor. Akademiya Nauk U.S.S.R., vyp. 8, 1946), A.B. Vistelius constructed a logarithmic correlation table and computed the correlation factor for the germanium content in ashes and the ash content of the Khumarinsk coals. This factor came to 0.52 ± 0.05. Accordingly, A.B. Vistelius concluded, in opposition to V.M. Ratynskiy, that "there is a definite correlative relationship between the germanium content in the Khumarinsk coals and their ash content; this relationship, for the first approximation of their logarithms, is linear."

This conclusion is erroneous. A.B. Vistelius studied the relationship between the germanium content in ashes and the ash content in coals, but he generalized his results for the ash content and germanium content in coal. According to V.M. Ratynskiy and others, the accumulation of germanium in coals is determined by its concentration by organic matter. Therefore, the germanium content in ashes is directly proportional to its content in the original coal and inversely proportional to its ash content. This relationship may be expressed as follows:

$$C_{ashes} = C_{coal}/A_c \times 100,$$

where C_{coal} is the germanium content in coal; C_{ashes} is the germanium content in the ashes

[7] Akademiya Nauk SSSR, Doklady, t. 53, no. 7, 1947, pp. 1455-1457.

[8] O stat'ye A.B. Visteliusa "novoye podtverzhdeniye nablyudeniy Gol'dshmidta o polozhenii germaniya v kamennykh uglyakh."

of the same coal; and A_c is the ash content in percent.

The formula shows the essential difference between the relationship established by A.B. Vistelius and that on which he generalized his conclusions.

Having recomputed the same data of V.M. Ratynskiy, for the germanium content in coal, and after having constructed a logarithmic correlation table by the A.B. Vistelius method, we obtained the correlation factor for the ash content in the coal and its germanium content. It came to 0.15 ± 0.1. This points to the lack of a correlative relationship between the ash content of the Khumarinsk coal and its germanium content, and confirms the error of A.B. Vistelius' conclusions.

It is pertinent to remark, in this connection, that our study of the Kizelovsk basin coals has revealed a correlation factor of 0.1 ± 0.11 for its ash and germanium contents, i.e., no relation at all.

Accordingly, the V.M. Ratynskiy conclusion that "there is no correlation between the germanium content and the ash content in a coal" is correct not only for the Khumarinsk but probably for other deposits.

CHRONICLE[1]

ON THE FORTHCOMING XXI SESSION OF THE INTERNATIONAL GEOLOGICAL CONGRESS[2]

by

The Bureau of the National Committee of the U. S. S. R. Geologists

On June 1, 1958, there was published the first circular of the Organization Committee, XXI Session of the International Geological Congress (I. G. C.), to be held in Copenhagen, August 15-25, 1960.

The Scandinavian countries are hosts for the session. Accordingly, the organization Committee consists of the representatives of Denmark, Norway, Finland, Sweden, and Iceland. The President is Arne Noe-Nigaard (Denmark); Secretary General, Theodor Sorgenfrei (Denmark).

The program includes 20 fields of study, and the sessions will be organized accordingly, as follows:

1) geochemical cycles; 2) geologic results of applied geochemistry and geophysics; 3) determination of the absolute age of pre-Quaternary geologic formations; 4) Tertiary chronology and climatology; 5) Cretaceous-Tertiary boundary; 6) pre-Quaternary micropaleontology; 7) Ordovician stratigraphy and correlation; 8) upper Precambrian and Cambrian stratigraphy; 9) Precambrian correlation; 10) marine geology; 11) regional and structural problems of petroleum geology; 12) regional paleogeography; 13) petrographic provinces, extrusive and metamorphic rocks; 14) the granite-gneiss problem; 15) genetic problems of uranium and thorium deposits; 16) genetic problems of ores; 17) mineralogy and origin of pegmatites; 18) structure of the earth's crust and the deformations of rocks; 19) Caledonian orogeny, 20) miscellaneous problems in geology.

The International Paleontological Union, the Association for Sedimentary Petrology, and some of the I. G. C. committees will meet during the session. The Organization Committee decided not to hold any symposia on various subjects, as had been the practice at previous sessions.

As previously established, the official languages of the XXI session will be English, French, German, Italian, Russian, and Spanish. However, all abstracts, in any of the official languages, shall be translated into English, which has been designated by the Organization Committee as the working language of the session. The length of the abstracts is not to exceed 200 words; of the papers, 5,000 words. The abstracts are to arrive at the Organization Committee not later than April 1, 1960; the full text, not later than September 1, 1959.

As suggested by the Committee, the papers should deal with major problems in Geology and important achievements in its several branches, or else contain hitherto unpublished data and facts bearing on broad fields of study.

The Committee hopes to have the abstracts and if possible the full texts printed or rototyped for the opening of the session. The discussions will be published later. This explains the deadlines for the abstracts and papers. The Committee reserves the right of the disposition of the incoming papers. The acceptance of a paper for presentation at the session does not necessarily mean its publication.

The Committee has outlined more than 50 field trips, chiefly taking place before the session: Greenland, 1; Iceland, 1; Norway, 18; Sweden, 16; Finland, 9; Denmark, 6. Some of the trips will cover two countries (for example, Sweden and Norway; Sweden and Denmark). The trips will illustrate general

[1] Khronika

[2] O predstoyashchey XXI sessii mezhdunarodnogo geologicheskogo kongressa.

features of regional geology, tectonics, volcanism, geomorphology, Quaternary geology, various problems in petrography (with emphasis on metasomatism and the granite-gneiss problem), geology of ores, stratigraphy and geology of the Precambrian, and lower Paleozoic and Mesozoic stratigraphy.

The participation of the Soviet geologists is being organized by the National Committee of the U. S. S. R. Geologists, affiliated with the Division of Geological-Geographical Sciences, the Academy of Sciences, U. S. S. R.

The Presidium of the Academy has confirmed the personnel of the National Committee, whose membership includes leading scientists from the several Institutes of the Academy, the Ministry of Geology and Conservation of Mineral Resources, the Academies of Sciences of the Union Republics, and geologic schools of higher education. Academician D. V. Nalivkin is chairman, with his alternates G. D. Afanas'yev, Corresponding Member Academy of Sciences; N. A. Belyayevskiy, Doctor of Geologic and Mineralogic Sciences; Academician K. I. Satpayev and Academician N. P. Semenenko of the Academy of Sciences, U. S. S. R. Members are Academicians A. G. Betekhtin, A. P. Vinogradov, D. S. Korzhinskiy, A. A. Polkanov, N. M. Strakhov, A. A. Trofimuk, N. S. Shatskiy, D. A. Shcherbakov; Corresponding Members of the Academy of Sciences U. S. S. R. Kh. M. Abdullayev, A. A. Amiraslanov, K. A. Vlasov, I. I. Gorskiy, M. F. Mirchink, P. M. Tatarinov; Academicians M. M. Aliyev, Azerb. S. S. R.; A. I. Dzhanelidze, Georgian S. S. R.; K. I. Lukashev, Belorussian S. S. R.; I. G. Magak'yan, Armenian S. S. R.; Yu. A. Dalinkevichyus, Corresponding Member of the Academy of Sciences, Lithuanian S. S. R.; V. I. Melnalksnis, Corresponding Member of the Academy of Sciences, Latvian S. S. R.; A. A. Bogdanov, Doctor of Geologic and Mineralogic Sciences (Moscow State University); V. A. Magnitskiy, Doctor of Geologic and Mineralogic Sciences (Moscow State University); Professor A. P. Markovskiy (All-Union Scientific Research Geologic Institute); Ye. T. Shatalov, Doctor of Geologic and Mineralogic Sciences (I. G. E. M., Academy of Sciences, U. S. S. R.); V. V. Fedynskiy, Doctor of Geologic and Mineralogic Sciences (Ministry of Geology and Mineral Conservation). The scientific secretary of the Committee, I. I. Katushenok, Candidate Geologic and Mineralogic Sciences (Academy of Sciences, U. S. S. R.).

The Presidium of the Academy of Sciences U. S. S. R. ratified the status of the National Committee of the U. S. S. R. Geologists. The status specifies that the committee is established in conformity with the resolution of the XX Session, International Geologic Congress, to promote the international communication of geologists between sessions, to direct the carrying out of those resolutions of the Congress which affect the U. S. S. R., and to make preparations for the current sessions.

The National Committee of Geologists is an interdepartmental organization. Among its tasks is the coordination of work of the Soviet geologists and geologic institutions participating in international commissions, associations, and unions for the solution of geologic problems requiring international cooperation. The Committee organizes the scientific communication of the U. S. S. R. geologists with international organizations and the national committees of other countries concerning the activity of the Congress and its standing committees, associations, and unions, and the participation in the international meetings and conferences of these organizations.

Interdepartmental state and local commissions for the preparation for the XXI session of the I. G. C. have been organized in some of the Union Republics and in large industrial centers. These commissions consider the applications for papers, discuss their subject and text, maps, and other material submitted by the institutions of a republic or region.

The National Committee has distributed the first circular of the Organization Committee. More than 700 titles have already been submitted by Soviet geologists. They are being considered by a group of curators for each field of study.

The National Committee proposes, in connection with the forthcoming XXI session, the publication of papers by Soviet geologists in the fields of study designated by the Congress. The papers must reach the Committee by March 15, 1959 (Academy of Sciences U. S. S. R., Lenin Prospect, Moscow, V-71).

The papers will be judged by groups of curators in the corresponding fields of study,[3] under the direction of A. P. Vinogradov (1), A. A. Saukov and V. V. Fedynskiy (2), I. Ye. Starik (3), V. I. Gromov (4), A. A. Yanshin (5), V. V. Menner (6), B. S. Sokolov (7), N. S. Shatskiy (8), A. A. Polkanov (9), P. A. Bezrukov (10), A. A. Trofimuk (11), A. B. Khabakov (12), G. D. Afanas'yev (13), N. P. Semenenko (14), A. D. Yershov (15), D. S. Korzhitskiy (16), G. P. Barsanov (17), A. V. Peyve (18), Ye. V. Pavlovskiy (19), N. A. Belyayevskiy (20).

---

[3] Figures in parentheses are the designated numbers for the fields of study, on p. 95.

In 1958, geologists of the U. S. S. R actively participated in international commissions of the I. G. C. on geologic, tectonic, and metallogenic maps of the world (Paris), the commission on abstracting the geologic literature (Paris, Heerlen), on Carboniferous stratigraphy, and on the geology and petrography of coal (Heerlen). In addition, a convention of the Carpathian-Balkan Association was held in Kiev and Lvov. Many problems associated with the forthcoming session and the carrying out of the resolutions of the preceding one were discussed at these meetings and conventions.

The National Committee hopes that Soviet geologists will take an active part in the preparation for the forthcoming XXI session, by submitting substantial reports in all fields of study designated by the Organization Committee, thereby contributing to the development of world geology and demonstrating the achievements of Soviet geology.

FIFTH SESSION OF THE INTERNATIONAL CONGRESS ON SEDIMENTOLOGY SWITZERLAND, JUNE 1-15, 1958[4]

by

L. V. Pustovalov

The purpose of the International Association for Sedimentology is the exchange of scientific experience in the study of sedimentary rocks and associated useful minerals, and of recent deposits.

To achieve this, the Association holds regular international congresses in various countries, where the participants become acquainted with the typical sedimentary formations of these countries and with some of the associated useful minerals.

The preceding sessions were held in Belgium (1946), France (1949), Holland (1951), and West Germany (1954).

The author attended the last session (Göttingen, West Germany) in the company of A. A. Zasukhin, Secretary-Interpreter.

As a result, the relations between the Association and the Academy of Sciences, U. S. S. R., were strengthened. At the Association's report to the International Petroleum Congress on the state of knowledge of sedimentary rocks in various countries. The L. V. Pustovalov report on this subject in the U. S. S. R. was published by the Association, along with similar reports from other countries.[5] Working relations between the two institutions were also established in other fields.

At the very first meeting of the Fifth Session of the International Congress on Sedimentology, in Geneva, June 2, 1958, Secretary-General Professor A. Vatan (Petroleum Institute of France, Paris) noted in his report the participation of Soviet geologists in the work of the Association.

The delegation of the Academy of Sciences, U. S. S. R., to the Fifth Session included L. V. Pustovalov, Corresponding Member, Academy of Sciences U. S. S. R. (leader of the delegation); P. L. Bezrukov (Oceanology Institute, Academy of Sciences U. S. S. R.; B. N. Mitreykin, S. G. Sarkisyan (Petroleum Institute, Academy of Sciences U. S. S. R.); I. V. Khvorova (Geologic Institute, Academy of Sciences U. S. S. R.), and V. I. Ayvazova (secretary-interpreter).

In addition, a group of Soviet scientists went to Switzerland as tourists, to participate in the Congress. They were A. M. Akhramkhodzhayev (Academy of Sciences, Uzbek S. S. R.); B. I. Danchev, A. G. Kossovskaya (Geologic Institute, Academy of Sciences U. S. S. R.); L. B. Rukhin (Professor, Leningrad State University); G. I. Teodorovich (Petroleum Institute, Academy of Sciences U. S. S. R.); and V. D. Shutov (Geologic Institute, Academy of Sciences, U. S. S. R.).

The Soviet scientist-tourists actively participated in the Congress, alongside the members of the official delegation.

At the closing meeting of the Congress, at Lausanne, June 5, 1958, the leaders of the Congress voiced their satisfaction with the size and the quality of membership of the Soviet delegation and on its participation in the work of the session.

The Fifth Session, as the preceding ones, was well attended. The official roster counted 171 participants, but the actual number was considerably greater, because the meetings (and some of the field trips) were attended also by many Swiss scientists, chiefly from the Universities of Geneva and Lausanne.

The membership represented 21 countries: Austria, England (including Scotland), Afghanistan, Belgium, Brazil, Holland, Denmark, West Germany, India, Iran, Spain, Italy,

[4] Pyataya sessiya mezhdunarodnogo kongressa po sedimentologii v shveytsarii (1-15 iyunya 1958).

[5] Bibliographie européenne des progrès récents de la sedimentologie. Revue de l'Institut Français du pétrole, v. X, 1955.

Lybia, Morocco, U. S. S. R., U. S. A., Tunisia, Turkey, France (including Algeria), Switzerland, and Sweden. Present were some outstanding scientists such as Professor K. Korrens, Director of the Institute of Sedimentary Petrography, Göttingen, West Germany; noted oceanologist F. Shepard, U. S. A.; Professor R. Ditz (England), Professor P. Kuenen (Holland); Professor A. Lombard (Switzerland); Professor A. Bercier (Switzerland); Professor P. Mercier (Switzerland); Professor J. Tercier, (Switzerland); Professor A. Vatan (France); Professor C. Emery (U. S. A.), and others.

The Congress was well organized. This was the result to a considerable extent to the Swiss location which is known for its tourist accommodations.

The Organization Committee had ready a collection of the abstracts and of brief itineraries of the field trips with index maps indicating the geologic structure of the country.

The subject matter at the Fifth Session (especially the field trips) was chiefly the problem of molasse and flysch, because Switzerland, by virtue of its position in the Alpine zone, is the classic locality for these deposits. However, many papers on other sedimentary topics were read at the session.

The reading and discussion of papers took three morning and two afternoon sessions (i. e., only 2. 5 working days). The Congress was divided into three sections: A -- modern sedimentation; b -- flysch sedimentation; and C -- molasse sedimentation.

A few joint sessions were held (A and B; B and C).

The meetings were presided over by the representatives of various countries, in rotation, including the U. S. S. R. (Professor S. G. Sarkisyan presided over the A and B joint session, June 3).

More than 100 papers were listed in the program. Only about 50 were read; the authors of the others were not present.

Although the session was dedicated chiefly to the problem of flysch and molasse, only a total of 17 papers dealt with this subject. Of the remaining papers, 7 were on modern sedimentation; 4 on terrigenous mineralogy; 1 on terminology; 1 on the luminescent method of study; 21 on miscellaneous subjects (petrography of coal-bearing deposits and bituminous, saline, glauconitic, pebble, carbonate, red, and other deposits; facies analysis, etc.).

It is not to be denied that the content of the papers was rather motley, which is the case in all international scientific congresses. The field trips, on the other hand, were oriented toward the problem of the Alpine flysch and molasse. Inasmuch as the field trips were the backbone of the Session, interest was focused on this subject despite the diversified character of the papers.

Prior to the Session, Soviet scientists submitted 16 papers to the Organization Committee, which is more than 15 percent of the total.

Eight out of the 16 papers were read in the meetings: P. L. Bezrukov's, on the results of the geologic study of deep submarine canyons in the northwestern Pacific, by the "Vityaz" expedition; on the zonation in the structure of terrigenous deposits on platforms and in geosynclines, by A. G. Kossovskaya and V. D. Shutov; on the formation of secondary deposits of sedimentary ores, by L. V. Pustovalov; on the significance of sedimentary breaks, by L. B. Rukhin; on the petrographic and mineralogic studies in the petroleum industry, U. S. S. R., by S. G. Sarkisyan; on the Upper Permian molasse of the Cis-Uralian region, by S. G. Sarkisyan; on the results of study of dolomite rocks in the U. S. S. R., by G. I. Teodorovich; and on carbonate flysch in Permian molasse of the Urals by T. V. Khvorova. All papers by Soviet geologists evoked great interest, which was manifest both in the meetings and in subsequent private conferences.

The remaining eight papers by Soviet scientists (N. B. Vassoyevich, V. V. Veber, M. V. Klenova, G. F. Krasheninnikov, Ye. V. Rukhina, N. M. Strakhov, and M. S. Shvetsov) were not read because of the absence of the authors (the same was true for the other absentees).

All of the 16 papers by Soviet scientists have been accepted by the Organization Committee for publications in the Transactions of the Fifth Session.

Seven and a half days were spent in six field trips, lasting 1/2 to 2 days each. Their itineraries were as follows:

Trip A: the Geneva area, with a detour to the French territory. Leader, Professor A. Lombard.

Trip B: Geneva-Thonon (France); Thonon-Lausanne (over Lake Geneva). Leader, Professor A. Lombard.

Trip C: Lausanne--Boulle--Gruier--Vevey; Vevey--Lausanne (over Lake Geneva). Leaders, Professor A. Bercier and H. Badout.

Trip D: Lausanne--Mount Pelerine--Bou-
:ret; Bouveret--Lausanne (over Lake Geneva ith a detour to the Rhone mouth). Leader, ·ofessor A. Bercier.

Trip E-1: Lausanne--Gstaad--Bernerhoff; :rnerhoff--Bern. Leader, Professor A. Ber- er.

Trip E-2: the Bern area. Leader Professor . Routch.

The total combined length of the field trips about 550 to 600 km, spread in a fairly ose network over the western part of vitzerland, and forming a triangle with the ise at Geneva Lake--Bern Alps, in the outh, and the apex at Bern, in the north. his enabled the participants to get first hand 10wledge of the Alpine flysch and molasse :posits throughout a considerable area of eir development.

Two schools of thought on the origin of e flysch were represented at the Congress.

One of them, with the claim of novelty, (perimental substantiation, and perhaps of iiversality, was championed by Professor P. uenen (Holland) whose paper was accom- inied by a film.

Professor Kuenen believes that the flysch :posits originated in the so-called turbidity ensity) currents which periodically carried ·eat amounts of clastic material into the :dimentary basins. The deposition of this aterial was responsible for the flysch with s typical alternation of definite "sets" of cies. The climatic factor is supposed to : predominant in this process, with the ctonic factor decidedly subordinate. Some lherents of Kuenen's school go so far as to :ny any part for tectonics in the formation the flysch.

Professor Kuenen reproduced turbidity ırrents under laboratory conditions and udied the resulting deposits. His experi- ents, shown by moving pictures, confirm, his opinion, the possibility of the forma- on of flysch deposits from periodically ırging turbidity currents.

The other school of thought includes most the Swiss geologists and was demonstrated field trip C.

According to this school, the main fac- rs in the deposition of flysch and molasse e as follows:

a) a syntectonic deposition of clastic aterial of an exclusively Alpine origine. In is connection, some of the participants ıggested that terms "flysch" and "molasse" be regarded as purely local, applicable to the Alpine province alone, and without a general facies meaning;

b) rapid submergence of the sedimentation area;

c) a supplementary effect of the climate, which changed during the Alpine orogeny and led to an acceleration or a slowing down of the sedimentary process.

It has been accepted that, even though the flysch and molasse deposits attain a thick- ness of many thousand meters, their accumu- lation always occurred in shallow basins, com- commonly beyond the reach of waves and outside a true marine environment. The flysch and molasse accumulations were ac- companied by an alteration of marine and lacustrine conditions and, consequently, by changes in salinity. It is regarded as taking place in paralic basins, with their isolated segments affected by floods and the erratic Alpine streams, with temporarily dry stretches between them. Clastic material was deposited in the areas of these erratic strea streams and of sluggish currents. Locally, the deposited material was washed out and its thickness cut down. Again, the advancing sea was responsible for deep local washouts which hamper detailed correlation of individ- ual sections. A periodic invasion of the sea is regarded as a prerequisite for flysch for- mation, because of the latter's cyclicity.

Each area and each period of flysch and molasse formation are marked by specific features of their own (the effect of migrating streams, etc.), which accounts for their local lateral and vertical differences.

Swiss geologists have studied in detail the succession of rocks within a cycle. They recognize "ideal" cycle, "full", and "abbre- viated" or "minor" cycles, and they empha- size that the cyclic structure is the main feature of the flysch and molasse deposits. Although a cycle is not a general correla- tive unit, it may be used as such in local stratigraphic correlation (within one and even more basins).

These concepts of the Swiss geologists on flysch and molasse formation are fairly close to those held by Soviet geologists.

It should be noted that some of the aspects of these deposits (the nature and the use of the flysch "markers", the method of corre- lation, etc.) were more fully covered in the works of the Soviet geologists (N. B. Vassoye- vich and others) than in those of the Swiss scientists.

The election of the Bureau of the Inter-

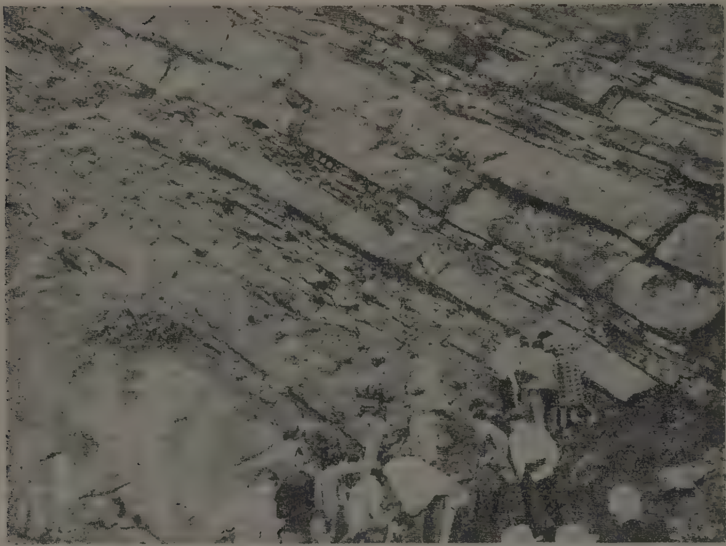


FIGURE 1. Flysch outcrops in the vicinity of Anmas (Haut Savoy).

Photo by the author.

national Association for Sedimentology was held during the final session, June 5, 1958.

Representing a group of foreign scientists, Professor K. Korrens (West Germany) submitted the following ticket: President, F. Shepard (U. S. A.); Secretary-General, A. Vatan (France); Members: P. Allen (England), A. Bercier (Switzerland); D. Duglas (Holland); K. Korrens (West Germany); L. V. Pustovalov (U. S. S. R.); A. Riviere (France). The entire slate was unanimously elected.

The place and time of the next session was then discussed. It was decided to hold it in Copenhagen in 1960, simultaneously with the XXI Session of the International Geological Congress.

It should be mentioned, in conclusion, that the Soviet delegation brought the most important Soviet literature on sedimentary rocks of the last few years. It was on exhibition during the Session, first at the Geneva then at the Lausanne universities. The exhibition attracted great attention among foreign scientists.

The exhibited material was presented by the Soviet delegation to the University of Lausanne.

PROBLEMS OF THE PETROLOGY OF COAL AND OF THE LITHOLOGY OF COAL MEASURES AT INTERNATIONAL CONGRESSES AT HEERLEN, HOLLAND, 1958[6]

by

V. S. Yablokov

The First International Congress on the petrology of coal was held September 10 to 13, 1958; the IV International Congress on Carboniferous Stratigraphy and Geology was held there on September 15 to 20.

The Congress on the petrology of coals had been organized by the International Committee, set up by the Third Congress on Carboniferous Stratigraphy and Geology, in 1951.

Expanded sessions were organized in 1953, 1955, and 1957 for a discussion of various problems in the petrology of coals and in palynology.

Soviet scientists first participated on the Committee in 1955. They were A. A. Lyuber

[6]Voprosy uglepetrologii i litologii uglenosnykh otlozheniy na mezhdunarodnykh kongressakh v kheyerlene (Gollandiya) v 1958.

Laboratory of Coal Geology, Academy of Sciences U. S. S. R.) and I. I. Ammosov (Mineral Fuel Institute, Academy of Sciences U. S. S. R.). The papers, read in sessions, are the results of the latest investigations in various countries and are of great interest to those engaged in the study of coal.[7]

Prior to the organization of the Committee, the problems of the petrology of coal were discussed in the meetings of the I, II, and III Congresses on Carboniferous Stratigraphy and Geology, initiated chiefly by the noted Dutch stratigrapher and paleobotanist, W. J. Jongmans, in 1928, 1935, and 1951, at Heerlen (Holland). Soviet geologists did not participate in the work of those congresses.

The program of the First International Congress on the Petrology of Coal, September 1958, included papers in two main fields of study: the general problems of the petrology of coal, the method of their study, their chemistry and technology; and the problems related to the study of spores from coal beds and coal measures.

About 100 representatives from 21 countries participated in the work of the First International Congress. Representing the Soviet Union were, Chairman of the delegation, I. I. Gorskiy (Corresponding Member, Academy of Sciences U. S. S. R.); I. I. Ammosov (Mineral Fuel Institute, Academy of Sciences U. S. S. R.); L. I. Bogolyubova (Geologic Institute, Academy of Sciences U. S. S. R.); B. Volkova, O. A. Dzens-Litovskaya, L. P. Nefed'yeva, O. A. Radchenko (Laboratory of Coal Geology, Academy of Sciences U. S. S. R.); and V. S. Yablokov (Geologic Institute, Academy of Sciences).

The Congress was opened with a welcoming address by A. A. Tyadens, Director of the Geologic Bureau at Heerlen, followed by an introductory address by Professor R. Potonie, Chairman of the Organization Committee. Meetings were held at the City Hall (Rathaus), presided over alternately by representatives of various countries: H. Fenton (England), M. Legrey (Belgium), R. Hacquebard (Canada), B. Alpern (France), D. Van-Krevelen (Holland), E. Stach (West Germany); V. S. Yablokov (U. S. S. R.), R. Potonie (West Germany).

In the first division, the following papers were read:

M. Th. Makovsky, Essen Coal Trust, West Germany, reported on the activity of the International Working Group for the methods of petrographic analysis. The results of three methods were given: the analysis of macerates, microlithotypes, and macrolithotypes. It was emphasized that a successful use of the method of study and statistics by microlithotypes requires first of all a single definition for them, which has not yet been achieved. The macerates analysis is the most simple, but requires the most time. The macrolithotype (Kohlenarten) analysis runs into difficulties if the analyzed material contains coals of different degrees of metamorphism. Reports were made also on the use of resins of definite reflecting capacity in the determination of the degree of metamorphism of coals in mixtures (the Van-Krevelen method), and of the application of methylene-iodide immersion in petrographic study (the Stach method). The comparison of different methods should be continued on various coals and briquets.

B. Alpern, of the Central Research Laboratory of the Coal Trust of France, reported on the work of the International Commission for Coal Petrography Nomenclature. The need for a systematization of the nomenclature was brought up on many occasions at previous coal petrographic conferences. In connection with the voluminous work of the last decade, in various fields of coal study, many new terms have appeared in the scientific literature, commonly understood and used in different ways. This is very inconvenient, as it hampers a ready correlation of the results obtained in different countries. The Commission spent much effort in the analysis and unification of these terms. It was decided to compile an international glossary on the petrography of coal, first for solid mineral fuels, described in Europe as "hard coals" and in America as "bituminous coals or anthracites." Individual pages of this glossary began to appear in 1957, in a special loose-leaf binder, with space for additional pages. The glossary has three sections: G -- general terms; P -- special terms for the petrography of coal; and B -- botanical terms used in coal petrography. The terms are indexed in a decimal system. Each term has the name of its author and the principle behind its origin, synonyms and analogues, with a description of the corresponding substance and its characteristic according to various study methods (sometimes with photomicrographs), along with the locality of its occurrence, and its uses. Prior to publication, the text for each term is discussed and approved by the commission.

The Nomenclature Commission met while the Congress was in session. At that meeting, G. H. Cady spoke on the reaction of the American coal petrographers to the correla-

[7] Proceedings of the International Committee for coal petrology, No. 1, 1954 and No. 2, 1956: Colloque international de pétrologie, appliquée des charbons. Revue de l'Industrie minéral, numero spécial. Juillet, 1958.

tion of the European and American coal-petrographic nomenclatures. Discussed and approved for publication were the explanations of such terms as cannel coal, boghead, sapropelitic coal, anthraxylon, brown substance, sporinite, autochtony, allochtony, etc. The Belgian scientists, M. Legraye and R. Noel were elected Chairman and Secretary of the subcommission, respectively.

D. G. Murchison, Durham University, England, reported on the results of an extensive experimental study of the precision and significance of the personal factor in the determination of the reflecting capacity, with the Berek microphotometer.

M. R. Feys of the Geologic and Geophysical Research Bureau, Paris, provided data on the accumulation of modern marine algae and on the possibility of some of the Paleozoic and Mesozoic coals having been formed from algae.

G. H. Taylor and S. Warne, of the Laboratory of Coal, Chetwood, (Australia), described the results of the study of some Australian coals, their correlation features, mineral impurities, etc.

P. Vetter, of the Aquitanian Basin Geologicas Service, France, spoke on some physical chemical properties of the microcomponents in the vitrain and durain coal groups. The consistency and the lack of it in the macerates of the same coal bed were established. The sulfur content and the fusing temperature were among the studied characteristics.

B. Ionesku-Siseti, The Enery Institute, Academy of Sciences Romanian People's Republic, Bucharest, communicated the results of the study of Romanian brown and hard coals and noted the necessity for a detailed study of various microcomponents for an explanation of the origin of coals and of their properties.

G. H. Cady, Illinois Geological Survey, U. S. A., made an interesting review of the progress in applied anthracology ("The American term for coal petrography and petrology in America." Editor). He commented briefly on the principal tasks accomplished in the laboratories of the Bureau of Mines, Illinois Geological Survey, the coal laboratory of the Ohio Geologic Survey, the Department of Coal at the University of Pennsylvania, and the coal laboratory of the Canadian Geological Survey, Sidney, Nova Scotia. The study of the petrography of coal in the U. S. A. was initiated in 1931, by R. Thissen who laid the foundation of the American coal-petrographic school.

D. W. Van-Krevelen, F. I. Huntjiens, H. N. M. Dormans, Central Laboratory, State Coal Trust, Heleen, Holland, reported on the results of study of the calorific properties of some carbonaceous macerates (vitrinite and fusinite).

P. A. Hacquebard, Canadian Geological Survey, Coal Laboratory, Sidney, Nova Scotia, spoke on the value of a quantitative differentiation of vitrinite into the component stelinite and collinite, in the study of the petrography of coking coal. The experiments were performed on Carboniferous and Cretaceous coking coals.

K. Kötter, Essen Coal Trust, West Germany, reported on the methods of the qualitative microscopic analysis of the briquette-making products and of the briquettes.

H. Jacob, German Institute of Fuels, Freiburg, Saxony, East Germany, reported on coal-petrographic study with the object of an improvement of the quality of high-temperature brown coal coke.

Five papers were read by participants from the Soviet Union.

V. S. Yablokov and L. I. Bogolyubova (Geologic Institute, Academy of Sciences U. S. S. R.) set forth some of the results of a detailed study of Carboniferous coals of the Donbas, Moscow basin, and the Uralian Jurassic and Tertiary coals, of two types -- the telinite and collinite -- possessing various chemical and industrial properties. They also explained the necessity of a differentiation of the inert substance in micrinite (micrinite and semifusinite) and fusinite. All these types should be considered separately, in the petrographic study, the classification of coals, and in the determination of their uses.

I. I. Ammosov (Institute of Mineral Fuels, Academy of Sciences U. S. S. R.) reported on the material features of the petrographic components of isometamorphic coals. He noted that the substance of each petrographic component is at a different stage of transformation, at any stage of coal metamorphism.

V. S. Yablokov, assisted by I. E. Val'ts and A. I. Ginzburg, spoke on the work done in the U. S. S. R. on the compilation of coal atlases for various basins, and on the problems and methods of this major collection work. The finished atlases of the Moscow and Pechora basins were on exhibition. The goal of this project is a comprehensive atlas of the coal types of the U. S. S. R.

The paper of L. P. Nefed'yeva (Laboratory of Coal Geology, Academy of Sciences U. S. S. R.) dealt with the origin of thick coal

measures, as represented by the Ekibastuz, Gusinoozersk, and Kharanorsk deposits.

The paper by I. E. Val'ts (Laboratory of Coal Geology, Academy of Sciences U. S. S. R.) gave a detailed description of the microcomponents of humus coals which originated, according to the author, in various vegetable tissues and which have differing structures.

A total of seven papers was read in the division on the study of coal spores.

R. Potonie, Geologic Service of Northern Rhine-Westphalia, Krefeld, West Germany, spoke on the stratigraphic value of the spore taxonomy.

S. I. Dijkstra, Geological Bureau, Heerlen, reported on the study of Carboniferous spores from the Moscow basin coals.

M. A. Butterworth and I. N. Millott, National Coal Council, Chester, England, outlined the progress in the study of microspores from British coal beds.

J. Dubinger, Geological Laboratory, Toulouse, France, described the microspores from some Stephanian and Authinian deposits.

B. Alpern, I. Girardeau, and F. Trolard, Central Research Laboratory, Coal Trust of France, outlined the stratigraphic division of the Permian and Carboniferous of France, by microspores.

G. O. Kremp and I. O. Frederiksen, Palynological Laboratory, University of Pennsylvania, U. S. A., reported on the determination of coal lithotypes by the palynological method as demonstrated by a comparative study of spores and pollen from Tertiary brown coals of South Dakota and from upper Carboniferous beds of Pennsylvania. Definite floral zones are associated with different types of coal. Such study may be helpful in the determination of marsh conditions, and possibly in the clarification of causes for the several industrial properties of coals.

Representing the Soviet Union in this division was A. A. Lyuber (Laboratory of Coal Geology, Academy of Sciences U. S. S. R.) with his paper on the anthraconite spores of the Angara province.

Thus, out of 25 papers presented at the Congress, 6 were from the U. S. S. R., or 24 percent of the total. These papers by Soviet scientists provoked great interest and raised many questions which were discussed not only in the meetings but in lively outside conversations. Perhaps the greatest attention was attracted by the new technique of preparing transparent thin sections for highly metamorphosed coals, as successfully applied in the U. S. S. R., and by the work on the new coal atlas. The great importance of such an undertaking was noted, along with expressions of hope for its quick realization.

During the Congress, Soviet geologists were introduced to the work of several coal laboratories. I. I. Ammosov and V. S. Yablokov visited the Central Laboratory of the State Coal Trust, at Heerlen, which included five large coal shafts and several coke chemical plants. Director, Professor D. V. Van-Krevelen stated that this was the largest laboratory in Europe, located in a large special building, erected mostly in 1940, but still undergoing constant expansion. The grades and properties of coals are studied on a large scale, along with all possible ways of their utilization -- from briquetting to coke-making and the manufacture of synthetic products. Besides the several research departments possessing very modern equipment, there are assorted mechanical and experimental shops for the rapid turnout of new instruments. There is a large scientific library and a spacious dining room. The coal petrographic section of the laboratory is rather small but adequate for petrographic research. The Laboratory personnel numbers about 700.

During the trip in West Germany, L. I. Bogolyubova, O. A. Radchenko, L. P. Nefed'yeva, O. D. Dzens-Litovskaya, and I. B. Volkova became acquainted with the Central Trust Coal Petrographic Laboratory, Essen (Leader, M. Makovskaya) and the Coal Petrographic Laboratory, Geologic Administration for Northern Rhine-Westphalia, at Krefeld (Leaders, E. Stach and M. Teichmüller). The study of coal is carried on mostly by polished rather than by thin sections, with the use of X-ray spectrum and the electron microscope. Applied research in cooperation with coal chemists and technologists, is chiefly carried on in the first laboratory. In the second, strong emphasis is put on the problems related to the origin of coal.

All the laboratories are marked by a high degree of efficiency, good and convenient quarters, modern equipment, and a comparatively small number of workers in individual fields.

The Congress debated the question of the creation of an international union of coal petrologists and palynologists. Although the desirability of such an organization was generally recognized, no resolution was passed pending a clarification of some organizational details (chiefly the problem of financing, etc.). The International Commission was charged with the coordination of these problems

among the interested scientific institutions of various countries during the current year.

The problems pertaining to the study of coals were also discussed in a number of papers at the IV International Congress on Carboniferous Geology and Stratigraphy, which took place immediately after the Coal Petrography Congress, also in Heerlen, September 15 to 20.

E. Stach, Geologic Service of Northern Rhine-Westphalia, Krefeld, West Germany, reported on the activity of the International Commission on Coal Petrology and of the subcommittee on nomenclature and the methods of coal study. He also reviewed the work of the First International Congress on Coal Petrology. A comprehensive and interesting paper on the origin of coal was given by M. Teichmüller, Geological Service of Northern Rhine-Westphalia, Krefeld, West Germany. She outlined, in the light of the latest data, the geologic causes for the formation of marshes of various types, in peat bogs, and the problem of diagenesis and metamorphism of coals.

B. Alpern reported on the results of the palynological study as discussed at the First International Congress of Coal Petrologists. It should be noted that the study of spores abroad, is chiefly done simultaneously with coal petrographic work and mainly for the purpose of the correlation of coal beds, rather than for the solution of general and specific stratigraphic problems. In this connection, the Congress on the Petrography of Coal debated the question whether a committee on spores should be established. It was decided, however, that it would be more expedient to charge the Carboniferous Stratigraphy Congress with the organization of such a commission, and a resolution to that effect was passed. The committee was designated more broadly as "The International Committee on Paleozoic Microflora." R. Potonie (West Germany) was appointed Chairman, and B. Alpern (France) Secretary General. In addition, five regional secretaries were designated, including A. A. Lyuber (Laboratory of Coal Geology, Academy of Sciences, U. S. S. R.). The task of the Committee is the unification of the nomenclature according to the rules of botany, and the development of spore study methods.

O. Kuyl (Geological Bureau, Heerlen) reported on the results of the study of Eocene and Jurassic coals from some deep (as much as 5000 m) oil wells in the U. S. A., which confirmed the Hilt law. The deviation from this law, in the Donbas and Kuzbas, was explained by the possibility of a different geothermal gradient.

K. Monomakhov (The Coal Trust of France) communicated new data on the tectonics of a number of French coal basins, in connection with the phenomenon of the sudden ejection of coal and gas in shafts.

Besides these and other papers on general stratigraphy, the Congress heard papers on the study of the structure and the formation conditions of coal measures.[8]

M. Rutten, Holland, spoke on the general subject of "Deposits, Movement, and Time." The paper was in the form of a dialogue between two opponents.

A comprehensive paper on Carboniferous sandstones of the Illinois Basin, with much field data and their generalization, was given by P. Potter of the Illinois Geological Survey, U. S. A. There are more than 40 sandstone layers in a section of about 1300 m thick. Usually distinct are coarse-grained and cross-bedded basal sequences ("channel phase") and finer-grained sequences with a marine fauna ("stratified phase").

The results of a recent study of the Mississippi delta and of the formation there of peat deposits, were set forth in a well-substantiated paper by H. Fisk, U. S. A. Near New Orleans, the peat is about six meters thick and its age has been determined at 3,000 years, which makes the deposition rate of 20 to 30 cm, each 300 years.

W. Jessen, Geologic Service of Northern Westphalia, West Germany, had an extended paper on the Carboniferous sedimentation, with emphasis on the structure of cyclothems.

K. Fiege, Kiel University, West Germany, spoke on the typology and the origin of Carboniferous sedimentary cycles, with a detailed lithofacies and biofacies description of cycles of different type and magnitude.

There were two papers from the U. S. S. R.: that by V. S. Yablokov, L. N. Botvinkina and A. P. Feofilova (Geologic Institute, Academy of Sciences U. S. S. R.) on the significance of alluvial deposits in the structure of coal measures of the Donbas, Karaganda, and Moscow Basins; and that of G. F. Krasheninnikov (Moscow University) on the facies study of Paleozoic coal measures and on its practical application. The papers were illustrated by a large number of paleogeographic maps and cross sections and provoked much interest and discussion.

---

[8] The stratigraphic problems and the resolutions on Carboniferous stratigraphy are outlined in a paper by I. I. Gorskiy and D. L. Stepanov.

The problems of cycles were discussed at great length by A. P. Feofilova and L. N. Botvinkina, with Professor P. Michelau and others, during the trip to West Germany where the Westphalian section was examined in the Bochum area. It became clear, both from the papers and from discussions, that the differentiation of the Ruhr Carboniferous was done chiefly on the upper boundary of the sandstones, without a detailed facies analysis.

Of great interest was a comprehensive paper of I. I. Gorskiy, Correspondent Member, Academy of Sciences U. S. S. R., on the status of coal geology in the U. S. S. R. He described the coal reserves of the U. S. S. R., the organization of prospecting and geologic work, and the main theoretical and practical problems of coal geology and petrography.

Besides the trips to Belgium and West Germany, the stratigraphic purpose of which is not discussed in this paper, there was a trip to the western part of Holland, from Hilversum to Kudelstaart, with B. P. Hageman, the leader. Its purpose was for the acquaintance with recent and buried peat deposits. Because of the lack of exposures, the sections were studied from thin boreholes. It was clearly shown that, going about 30 m from east to west, a single peat layer, more than seven meters thick, splits in two, with an arenaceous and argillaceous sequence containing a marine fauna wedging out, in between. The boreholes have also outlined ancient channels of the Wecht River, which eroded the peat as the channels shifted.

In summarizing the work of the two Heerlen congresses, the following aspects may be noted:

1. A wide participation of many countries and the large number of the participants (as many as 200 for the Stratigraphic Congress).

2. The diversity and novelty of the material presented.

3. The active participation of Soviet geologists and the great interest displayed in their work. Also the personal contact with foreign scientists, and the acquaintance with their achievements.

A further participation in the works of various commissions will undoubtedly be of mutual benefit. It will bring even more productive results in the solution of the basic problems of coal petrology and the structure of coal measures.

THE CONTESTS FOR THE NAME PRIZES OF THE ACADEMY OF SCIENCES, U. S. S. R.[9]

by

The Division of the Geologic-Geographic Sciences,
Academy of Sciences, U. S. S. R.

The Division of Geologic-Geographic Sciences, Academy of Sciences, U. S. S. R., announces the following contests to be held in 1959, for the prizes awarded to Soviet scientists by the Presidium of the Academy.

1) the I. M. Gubkin Prize, in the amoung of 10,000 rubles, to be awarded for the best scientific work in the field of petroleum geology, exploration, and production of oil fields;

2) the F. P. Savarenskiy Prize, in the amount of 10,000 rubles, to be awarded for the best work in the field of hydrogeology and engineering geology.

The competing papers may be presented by scientific societies, scientific-research institutions, schools of higher learning, construction bureaus, academicians, and corresponding members of the Academy of Sciences, U. S. S. R.

Only published works are eligible for the name prizes.

The papers should be presented at the Division of Geologic-Geographic sciences (14, Lenin Prospect, Moscow V-71), inscribed, "The I. M. Gubkin (F. P. Savarenskiy) Prize Contest" in duplicate. They should be accompanied by the reviews of the paper by the scientific community, an abstract, and a brief biography of the contestant, with a list of his main scientific works and discoveries.

All papers should be in by September 15, 1959.

---

[9] O konkursakh na soiskaniye imennykh premiy Akademii Nauk SSSR.

TO THE AUTHORS[1]

1. Izvestiya of the Academy of Sciences, U. S. S. R. publishes papers in the geologic sciences: general and historic geology, tectonics, stratigraphy, petrography, mineralogy, geochemistry, lithology, the theory of ore and other minerals, and in the history of these disciplines.

The section, "Reviews and Discussions," contains discursive and critical articles on various geologic problems and reviews of published works.

The length of the papers should not be more than 25 to 30 typewritten pages.

2. Priority is given to papers on general theoretical problems of geology and to those read in the Division's meetings; next to geologic works performed in the Academy's Institutes.

The submitted material should be accompanied by a written authorization of the organization which financed the work, and by a proper certification as to its eligibility for publication in the Izvestiya, Geologic Series.

3. The submitted papers should be finally corrected, dated, and signed by the authors. No subsequent changes will be permitted.

The title of the paper should be followed by an abstract presenting the author's thesis supported by the material of the text.

4. The galleys are presented to the authors for control only. Stylistic corrections, additions, and deletions, or any changes in the text will not be accepted.

5. Only those manuscripts are accepted which come up to publication and printing standards. They should be clearly typed on one side of white paper, impermeable to ink, double spaced. Handwritten and carbon manuscripts will not be accepted.

[1] Bnimahiyu avtorov.

6. The names of foreign authors, in the text, should be given in Russian transliteration.

7. Abbreviations, except for the common ones (such as 1 m, 2 kg, etc.) are unacceptable.

8. Latin names of fauna, formulas, and all foreign texts, should be typed or transcribed clearly and unmistakably. To avoid mistakes, a clean-cut distinction should be made between the upper and lower case letters, such as K, O, S, V, M, etc. by marking them with two lines below, for capital letters, and with two lines above for the lower case. All indices, exponents, and Greek letters should be carefully outlined, with corresponding marginal notations.

9. All units of measure should conform to the standard symbols (if there are such), according to the All-Union Standard V. K. S.

10. Numerical tables, such as of chemical, mineral, and other analyses should be individually certified by the author, with indication of the method of obtaining the data.

11. The literature cited is to be given, not in footnotes, but in a general list, at the end of the paper. The authors are listed in alphabetic order, the Russian sources first, and are so numbered. The reference in the text is marked by the corresponding number in parentheses.

12. The literature is cited in the following way: for books -- the name of the author, his initials, a full and precise title, the number of the volume, part, issue, the publication name and year; for magazines -- the author's name and initials; the title, the magazine name, number, and year; if necessary, the volume and issue number.

13. Illustration with maps, cross sections, and photomicrographs is admissible only when they complement the text and are indispensable for the author's thesis. Any graphic

material which has no direct bearing on the subject of the paper will not be accepted.

14. The illustrations should be appended to the manuscript, with all items numbered and accompanied by a list of legends. A minimum of numerical and letter symbols, corresponding to the text, should be used in the illustrations. Their explanations should be given in the legend.

15. Places for the figures and tables should be indicated in the manuscript.

16. The reverse of each illustration should carry its number, the author's name, and the title.

17. The manuscript pages should be numbered and if possible, bound in a folder. The illustrations and legends should be placed in a separate envelope.

The author's name, his address and telephone number should be given at the end of the manuscript, or on the folder.

Izvestiya Akademii Nauk, Seriya Geologicheskaya; 35, Staromonetnyy Pereulok, Moscow 17, Room 244; Tel. V-1-05-08, Ext. 98.